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2018

PARTICLE PHYSICS BOOKLET

Extracted from the *Review of Particle Physics*
M. Tanabashi *et al.* (Particle Data Group),
Phys. Rev. D 98, 030001 (2018).

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The publication of the *Review of Particle Physics* is supported by the Director, Office of Science, Office of High Energy Physics of the U.S. Department of Energy under Contract No. DE–AC02–05CH11231; by the European Laboratory for Particle Physics (CERN); by an implementing arrangement between the governments of Japan (MEXT: Ministry of Education, Culture, Sports, Science and Technology) and the United States (DOE) on cooperative research and development; and by the Italian National Institute of Nuclear Physics (INFN). Individual collaborators receive support for their PDG activities from their respective funding agencies.

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PARTICLE DATA GROUP

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* This *Particle Physics Booklet* includes the Summary Tables plus essential tables, figures, and equations from selected review articles. The table of contents, on the following pages, lists also additional material available in the full *Review*.

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The following are found only in the full *Review*, see

`http://pdg.lbl.gov`

VOLUME 1: SUMMARY TABLES AND REVIEWS

Table 1.1. Reviewed 2015 by P.J. Mohr and D.B. Newell (NIST). Mainly from CODATA recommended values, Rev. Mod. Phys. **88**, 035009 (2016). The last group, beginning with the Fermi coupling constant, comes from Particle Data Group 2018 update. The 1-σ uncertainties in the last digits are given in parentheses after the values. See the full edition of this *Review* for references and further explanation.

Quantity	Symbol, equation	Value	Uncertainty (ppb)
speed of light in vacuum	c	299 792 458 m s^{-1}	exact
Planck constant	h	6.626 070 040(81)$\times10^{-34}$ J s	12
Planck constant, reduced	$\hbar \equiv h/2\pi$	1.054 571 800(13)$\times10^{-34}$ J s	12
		$=$ 6.582 119 514(40)$\times10^{-22}$ MeV s	6.1
electron charge magnitude	e	1.602 176 6208(98)$\times10^{-19}$ C $=$ 4.803 204 673(30)$\times10^{-10}$ esu	6.1, 6.1
conversion constant	$\hbar c$	197.326 9788(12) MeV fm	6.1
conversion constant	$(\hbar c)^2$	0.389 379 3656(48) GeV^2 mbarn	12
electron mass	m_e	0.510 998 9461(31) MeV/c^2 $=$ 9.109 383 56(11)$\times10^{-31}$ kg	6.2, 12
proton mass	m_p	938.272 0813(58) MeV/c^2 $=$ 1.672 621 898(21)$\times10^{-27}$ kg	6.2, 12
		$=$ 1.007 276 466 879(91) u $=$ 1836.152 673 89(17) m_e	0.090, 0.095
deuteron mass	m_d	1875.612 928(12) MeV/c^2	6.2
unified atomic mass unit (u)	(mass ^{12}C atom)/12 $=$ (1 g)/(N_A mol)	931.494 0954(57) MeV/c^2 $=$ 1.660 539 040(20)$\times10^{-27}$ kg	6.2, 12
permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	8.854 187 817 ... $\times10^{-12}$ F m^{-1}	exact
permeability of free space	μ_0	$4\pi \times 10^{-7}$ N A^{-2} $=$ 12.566 370 614 ... $\times10^{-7}$ N A^{-2}	exact
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	7.297 352 5664(17)$\times10^{-3}$ $=$ 1/137.035 999 139(31)	0.23, 0.23
		At $Q^2 = 0$. At $Q^2 \approx m^2(W)$ the value is $\sim$ 1/128.	
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	2.817 940 3227(19)$\times10^{-15}$ m	0.68
(e^- Compton wavelength)/2π	$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$	3.861 592 6764(18)$\times10^{-13}$ m	0.45
Bohr radius ($m_{\rm nucleus} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	0.529 177 210 67(12)$\times10^{-10}$ m	0.23
wavelength of 1 eV/c particle	$hc/(1\text{ eV})$	1.239 841 9739(76)$\times10^{-6}$ m	6.1
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$	13.605 693 009(84) eV	6.1
Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	0.665 245 871 58(91) barn	1.4

Bohr magneton	$\mu_B = e\hbar/2m_e$	$5.788\ 381\ 8012(26) \times 10^{-11}$ MeV T^{-1}	0.45
nuclear magneton	$\mu_N = e\hbar/2m_p$	$3.152\ 451\ 2550(15) \times 10^{-14}$ MeV T^{-1}	0.46
electron cyclotron freq./field	$\omega^e_{\text{cycl}}/B = e/m_e$	$1.758\ 820\ 024(11) \times 10^{11}$ rad s^{-1} T^{-1}	6.2
proton cyclotron freq./field	$\omega^p_{\text{cycl}}/B = e/m_p$	$9.578\ 833\ 226(59) \times 10^{7}$ rad s^{-1} T^{-1}	6.2
gravitational constant	G_N	$6.674\ 08(31) \times 10^{-11}$ m^3 kg^{-1} s^{-2}	4.7×10^4
		$= 6.708\ 61(31) \times 10^{-39}$ $\hbar c$ $(\text{GeV}/c^2)^{-2}$	4.7×10^4
standard gravitational accel.	g_N	$9.806\ 65$ m s^{-2}	exact
Avogadro constant	N_A	$6.022\ 140\ 857(74) \times 10^{23}$ mol^{-1}	12
Boltzmann constant	k	$1.380\ 648\ 52(79) \times 10^{-23}$ J K^{-1}	570
		$= 8.617\ 3303(50) \times 10^{-5}$ eV K^{-1}	570
molar volume, ideal gas at STP	$N_A k(273.15\ \text{K})/(101\ 325\ \text{Pa})$	$22.413\ 962(13) \times 10^{-3}$ m^3 mol^{-1}	570
Wien displacement law constant	$b = \lambda_{\max} T$	$2.897\ 7729(17) \times 10^{-3}$ m K	570
Stefan-Boltzmann constant	$\sigma = \pi^2 k^4/60\hbar^3 c^2$	$5.670\ 367(13) \times 10^{-8}$ W m^{-2} K^{-4}	2300
Fermi coupling constant	$G_F/(\hbar c)^3$	$1.166\ 378\ 7(6) \times 10^{-5}$ GeV^{-2}	510
weak-mixing angle	$\sin^2 \widehat{\theta}(M_Z)$ ($\overline{\text{MS}}$)	0.231 22(4) (0.23155(5) for effective angle)	1.7×10^5
$W^{\pm}$ boson mass	m_W	80.379(12) GeV/c^2	1.5×10^5
Z^0 boson mass	m_Z	91.1876(21) GeV/c^2	2.3×10^4
strong coupling constant	$\alpha_s(m_Z)$	0.1181(11)	9.3×10^6

$\pi = 3.141\ 592\ 653\ 589\ 793\ 238$ e $= 2.718\ 281\ 828\ 459\ 045\ 235$ $\gamma = 0.577\ 215\ 664\ 901\ 532\ 861$

1 in $\equiv$ 0.0254 m	1 G $\equiv 10^{-4}$ T	1 eV $= 1.602\ 176\ 6208(98) \times 10^{-19}$ J	kT at 300 K $= [38.681\ 740(22)]^{-1}$ eV
1 Å $\equiv$ 0.1 nm	1 dyne $\equiv 10^{-5}$ N	1 eV/c^2 $= 1.782\ 661\ 907(11) \times 10^{-36}$ kg	0 °C $\equiv$ 273.15 K
1 barn $\equiv 10^{-28}$ m^2	1 erg $\equiv 10^{-7}$ J	$2.997\ 924\ 58 \times 10^9$ esu = 1 C	1 atmosphere $\equiv$ 760 Torr $\equiv$ 101 325 Pa

2. Astrophysical Constants and Parameters

Table 2.1. Revised October 2017 by D.E. Groom (LBNL) and D. Scott (University of British Columbia). Figures in parentheses give 1-σ uncertainties in last place(s). This table does not represent a critical review and is not intended as a primary reference. See the full *Review.*

Quantity	Symbol, equation	Value	Reference, footnote
Newtonian constant of gravitation	G_N	$6.674\,08(31) \times 10^{-11}$ m^3 kg^{-1} s^{-2}	[1]
Planck mass	$\sqrt{\hbar c/G_N}$	$1.220\,910(29)\times 10^{19}$ GeV/c^2 = $2.176\,47(5)\times 10^{-8}$ kg	[1]
Planck length	$\sqrt{\hbar G_N/c^3}$	$1.616\,229(38) \times 10^{-35}$ m	[1]
tropical year (equinox to equinox) (2011)	yr	$31\,556\,925.2$ s $\approx \pi \times 10^7$ s	[4]
sidereal year (fixed star to fixed star) (2011)		$31\,558\,149.8$ s $\approx \pi \times 10^7$ s	[4]
mean sidereal day (2011) (time between vernal equinox transits)		$23^{\rm h}\,56^{\rm m}\,04\overset{\rm s}{.}090\,53$	[4]
astronomical unit	au	$149\,597\,870\,700$ m	exact [5]
parsec (1 au/1 arc sec)	pc	$3.085\,677\,581\,49 \times 10^{16}$ m = $3.262\ldots$ ly	exact [6]
light year (deprecated unit)	ly	$0.306\,6\ldots$ pc = $0.946\,053\ldots \times 10^{16}$ m	
Solar mass	$M_\odot$	$1.988\,48(9) \times 10^{30}$ kg	[7]
Schwarzschild radius of the Sun	$2G_N M_\odot/c^2$	$2.953\,250\,24$ km	[8]
nominal Solar equatorial radius	$R_\odot$	6.957×10^8 m	exact [9]
nominal Solar luminosity	$L_\odot$	3.828×10^{26} W	exact [9,11]
Earth mass	$M_\oplus$	$5.972\,4(3) \times 10^{24}$ kg	[7]
Schwarzschild radius of the Earth	$2G_N M_\oplus/c^2$	$8.870\,056\,580(18)$ mm	[12]
nominal Earth equatorial radius	$R_\oplus$	$6.378\,1 \times 10^6$ m	exact [9]
jansky (flux density)	Jy	10^{-26} W m^{-2} Hz^{-1}	definition
luminosity conversion	L	$3.0128 \times 10^{28} \times 10^{-0.4\,M_{\rm bol}}$ W	[13]
		($M_{\rm bol}$ = absolute bolometric magnitude = bolometric magnitude at 10 pc)	
flux conversion	$\mathscr{F}$	$2.5180 \times 10^{-8} \times 10^{-0.4\,m_{\rm bol}}$ W m^{-2}	[13]
		($m_{\rm bol}$ = apparent bolometric magnitude)	
ABsolute monochromatic magnitude	AB	$-2.5\log_{10} f_\nu - 56.10\,[+8.90]$, f_ν in W m^{-2} Hz^{-1} [in Jy]	[14]
Solar angular velocity around the Galactic center	Θ_0/R_0	30.3 ± 0.9 km s^{-1} kpc^{-1}	[15]
Solar distance from Galactic center	R_0	8.00 ± 0.25 kpc	[15,16]
circular velocity at R_0	v_0 or Θ_0	$254(16)$ km s^{-1}	[15]
escape velocity from Galaxy	$v_{\rm esc}$	498 km/s $< v_{\rm esc} <$ 608 km/s	[17]
local disk density	$\rho_{\rm disk}$	3–12 $\times 10^{-24}$ g cm^{-3} $\approx$ 2–7 GeV/c^2 cm^{-3}	[18]
local dark matter density	ρ_χ	canonical value 0.3 GeV/c^2 cm^{-3} within factor 2–3	[19]

present day CMB temperature	T_0	$2.7255(6)$ K	[20,21]
present day CMB dipole amplitude	d	$3.3645(20)$ mK	[20,22]
Solar velocity with respect to CMB	$v_\odot$	$370.09(22)$ km s^{-1} towards $(\ell, b) = (263.00(3)^\circ, 48.24(2)^\circ)$	[22]
Local Group velocity with respect to CMB	$v_{\rm LG}$	$627(22)$ km s^{-1} towards $(\ell, b) = (276(3)^\circ, 30(3)^\circ)$	[20,23]
number density of CMB photons	n_γ	$410.7(T/2.7255)^3$ cm^{-3}	[24]
density of CMB photons	ρ_γ	$4.645(4)\,(T/2.7255)^4 \times 10^{-34}\,{\rm g\,cm^{-3}} \approx 0.260\,{\rm eV cm^{-3}}$	[24]
entropy density/Boltzmann constant	s/k	$2\,891.2\ (T/2.7255)^3$ cm^{-3}	[24]
present day Hubble expansion rate	H_0	$100\ h$ km s^{-1} Mpc^{-1} $= h \times (9.777\,752$ Gyr$)^{-1}$	[25]
scale factor for Hubble expansion rate	h	$0.678(9)$	[2,26]
Hubble length	c/H_0	$0.925\,0629 \times 10^{26}\,h^{-1}$ m $= 1.374(18) \times 10^{26}$ m	
scale factor for cosmological constant	$c^2/3H_0^2$	$2.85247 \times 10^{51}\,h^{-2}$ m^2 $= 6.20(17) \times 10^{51}$ m^2	
critical density of the Universe	$\rho_{\rm crit} = 3H_0^2/8\pi G_N$	$1.878\,40(9) \times 10^{-29}\ h^2$ g cm^{-3}	
		$= 1.053\,71(5)\times 10^{-5}\ h^2\ ({\rm GeV}/c^2)$ cm^{-3} $= 2.775\,37(13)\times 10^{11}\,h^2\ M_\odot {\rm Mpc}^{-3}$	
baryon-to-photon ratio (from BBN)	$\eta = n_{\rm b}/n_\gamma$	$(5.8 \times 10^{-10} \le \eta \le 6.6 \times 10^{-10}$ (95% CL)	[27]
number density of baryons	$n_{\rm b}$	$2.503(26) \times 10^{-7}$ cm^{-3}	[2,3,28,29]
		$(2.4 \times 10^{-7} < n_{\rm b} < 2.7 \times 10^{-7})$ cm^{-3} (95% CL)	$\eta \times n_\gamma$
CMB radiation density of the Universe	$\Omega_\gamma = \rho_\gamma/\rho_{\rm crit}$	$2.473 \times 10^{-5} (T/2.7255)^4\,h^{-2} = 5.38(15) \times 10^{-5}$	[24]
baryon density of the Universe	$\Omega_{\rm b} = \rho_{\rm b}/\rho_{\rm crit}$	$^\ddagger\,0.02226(23)\,h^{-2}\ = {}^\dagger\,0.0484(10)$	[2,3,22]
cold dark matter density of the universe	$\Omega_{\rm c} = \rho_{\rm c}/\rho_{\rm crit}$	$^\ddagger\,0.1186(20)\,h^{-2}\ = {}^\dagger\,0.258(11)$	[2,3,22]
100 × approx to $r_*/D_{\rm A}$	$100 \times \theta_{\rm MC}$	$^\ddagger\,1.0410(5)$	[2,3]
reionization optical depth	τ	$^\ddagger\,0.066(16)$	[2,3,30]
scalar spectral index	$n_{\rm s}$	$^\ddagger\,0.968(6)$	[2,3]
ln pwr primordial curvature pert. (k_0=0.05 Mpc^{-1})	$\ln(10^{10}\Delta^2_{\mathcal{R}})$	$^\ddagger\,3.062(29)$	[2,3]
dark energy density of the Universe	Ω_Λ	$^\dagger\,0.692 \pm 0.012$	[2,3]
pressureless matter density of the Universe	$\Omega_{\rm m} = \Omega_{\rm c} + \Omega_{\rm b}$	$^\dagger\,0.308 \pm 0.012$	[2,3]
fluctuation amplitude at $8\,h^{-1}$ Mpc scale	σ_8	$^\dagger\,0.815 \pm 0.009$	[2,3]
redshift of matter-radiation equality	$z_{\rm eq}$	$^\dagger\,3365 \pm 44$	[2]
redshift at half reionization	$z_{\rm reion}$	$^\dagger\,8.8^{+1.7}_{-1.4}$	[2,33]
age of the Universe	t_0	$^\dagger\,13.80 \pm 0.04$ Gyr	[2]
effective number of neutrinos	$N_{\rm eff}$	$^\sharp\,3.13 \pm 0.32$	[2,34,35]
sum of neutrino masses	$\sum m_\nu$	$^\sharp$ <0.68 eV (Planck CMB); $\ge$ 0.05 eV (mixing)	[2,35,36,37]
neutrino density of the Universe	$\Omega_\nu = h^{-2} \sum m_{\nu_j}/93.04\,{\rm eV}$	$^\sharp$ < 0.016 (Planck CMB; $\ge$ 0.0012 (mixing)	[2,36,37]
curvature	$\Omega_{\rm K}$	$^\sharp\,-0.005^{+0.016}_{-0.017}$ (95%CL)	[2]
running spectral index slope, $k_0 = 0.002$ Mpc^{-1}	$dn_{\rm s}/d\ln k$	$^\sharp\,-0.003(15)$	[2]
tensor-to-scalar field perturbations ratio, k_0=0.002 Mpc^{-1}	$r = T/S$	$^\sharp$ < 0.114 at 95% CL; no running	[2,3,20,38]
dark energy equation of state parameter	w	-1.01 ± 0.04	[31,39]

SUMMARY TABLES OF PARTICLE PROPERTIES

Extracted from the Particle Listings of the
Review of Particle Physics
M. Tanabashi *et al.* (Particle Data Group),
Phys. Rev. D **98**, 030001 (2018)
Available at `http://pdg.lbl.gov`

(Approximate closing date for data: January 15, 2018)

GAUGE AND HIGGS BOSONS

γ (photon)

$I(J^{PC}) = 0,1(1^{--})$

Mass $m < 1 \times 10^{-18}$ eV
Charge $q < 1 \times 10^{-35}$ e
Mean life τ = Stable

g or gluon

$I(J^{P}) = 0(1^{-})$

Mass $m = 0$ [a]
SU(3) color octet

graviton

$J = 2$

Mass $m < 6 \times 10^{-32}$ eV

W

$J = 1$

Charge $= \pm 1$ e
Mass $m = 80.379 \pm 0.012$ GeV
W/Z mass ratio $= 0.88153 \pm 0.00017$
$m_Z - m_W = 10.803 \pm 0.015$ GeV
$m_{W^+} - m_{W^-} = -0.029 \pm 0.028$ GeV
Full width $\Gamma = 2.085 \pm 0.042$ GeV
$\langle N_{\pi^\pm} \rangle = 15.70 \pm 0.35$
$\langle N_{K^\pm} \rangle = 2.20 \pm 0.19$
$\langle N_p \rangle = 0.92 \pm 0.14$
$\langle N_{\text{charged}} \rangle = 19.39 \pm 0.08$

W^- modes are charge conjugates of the modes below.

W^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\ell^+\nu$	[b]	(10.86± 0.09) %		–
$e^+\nu$		(10.71± 0.16) %		40189
$\mu^+\nu$		(10.63± 0.15) %		40189
$\tau^+\nu$		(11.38± 0.21) %		40170

hadrons		(67.41 ± 0.27) %		–
$\pi^+\gamma$		$< 7 \times 10^{-6}$	95%	40189
$D_s^+\gamma$		$< 1.3 \times 10^{-3}$	95%	40165
cX		(33.3 ± 2.6) %		–
$c\overline{s}$		$(31 {}^{+13}_{-11})$ %		–
invisible	[c]	(1.4 ± 2.9) %		–

Z

$J = 1$

Charge = 0
Mass $m = 91.1876 \pm 0.0021$ GeV [d]
Full width $\Gamma = 2.4952 \pm 0.0023$ GeV
$\Gamma(\ell^+\ell^-) = 83.984 \pm 0.086$ MeV [b]
$\Gamma(\text{invisible}) = 499.0 \pm 1.5$ MeV [e]
$\Gamma(\text{hadrons}) = 1744.4 \pm 2.0$ MeV
$\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-) = 1.0009 \pm 0.0028$
$\Gamma(\tau^+\tau^-)/\Gamma(e^+e^-) = 1.0019 \pm 0.0032$ [f]

Average charged multiplicity

$\langle N_{charged} \rangle = 20.76 \pm 0.16$ (S = 2.1)

Couplings to quarks and leptons

$g_V^\ell = -0.03783 \pm 0.00041$
$g_V^u = 0.18 \pm 0.05$
$g_V^d = -0.35^{+0.05}_{-0.06}$
$g_A^\ell = -0.50123 \pm 0.00026$
$g_A^u = 0.50^{+0.04}_{-0.05}$
$g_A^d = -0.514^{+0.050}_{-0.029}$
$g^{\nu_\ell} = 0.5008 \pm 0.0008$
$g^{\nu_e} = 0.53 \pm 0.09$
$g^{\nu_\mu} = 0.502 \pm 0.017$

Asymmetry parameters [g]

$A_e = 0.1515 \pm 0.0019$
$A_\mu = 0.142 \pm 0.015$
$A_\tau = 0.143 \pm 0.004$
$A_s = 0.90 \pm 0.09$
$A_c = 0.670 \pm 0.027$
$A_b = 0.923 \pm 0.020$

Charge asymmetry (%) at Z pole

$A_{FB}^{(0\ell)} = 1.71 \pm 0.10$
$A_{FB}^{(0u)} = 4 \pm 7$
$A_{FB}^{(0s)} = 9.8 \pm 1.1$
$A_{FB}^{(0c)} = 7.07 \pm 0.35$
$A_{FB}^{(0b)} = 9.92 \pm 0.16$

***Z* DECAY MODES**		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
e^+e^-	[h]	(3.3632 ± 0.0042) %		45594
$\mu^+\mu^-$	[h]	(3.3662 ± 0.0066) %		45594
$\tau^+\tau^-$	[h]	(3.3696 ± 0.0083) %		45559

$\ell^+\ell^-$		[b,h]	(3.3658 $\pm$ 0.0023)	%		–
$\ell^+\ell^-\ell^+\ell^-$		[i]	(4.45 $\pm$ 0.32)	$\times 10^{-6}$		45594
invisible		[h]	(20.000 $\pm$ 0.055)	%		–
hadrons		[h]	(69.911 $\pm$ 0.056)	%		–
$(u\overline{u}+c\overline{c})/2$			(11.6 $\pm$ 0.6)	%		–
$(d\overline{d}+s\overline{s}+b\overline{b})/3$			(15.6 $\pm$ 0.4)	%		–
$c\overline{c}$			(12.03 $\pm$ 0.21)	%		–
$b\overline{b}$			(15.12 $\pm$ 0.05)	%		–
$b\overline{b}b\overline{b}$			(3.6 $\pm$ 1.3)	$\times 10^{-4}$		–
ggg			$<$ 1.1	%	CL=95%	–
$\pi^0\gamma$			$<$ 2.01	$\times 10^{-5}$	CL=95%	45594
$\eta\gamma$			$<$ 5.1	$\times 10^{-5}$	CL=95%	45592
$\omega\gamma$			$<$ 6.5	$\times 10^{-4}$	CL=95%	45590
$\eta'(958)\gamma$			$<$ 4.2	$\times 10^{-5}$	CL=95%	45589
$\phi\gamma$			$<$ 8.3	$\times 10^{-6}$	CL=95%	45588
$\gamma\gamma$			$<$ 1.46	$\times 10^{-5}$	CL=95%	45594
$\pi^0\pi^0$			$<$ 1.52	$\times 10^{-5}$	CL=95%	45594
$\gamma\gamma\gamma$			$<$ 2.2	$\times 10^{-6}$	CL=95%	45594
$\pi^\pm W^\mp$		[j]	$<$ 7	$\times 10^{-5}$	CL=95%	10167
$\rho^\pm W^\mp$		[j]	$<$ 8.3	$\times 10^{-5}$	CL=95%	10142
$J/\psi(1S)X$			(3.51 $^{+0.23}_{-0.25}$)	$\times 10^{-3}$	S=1.1	–
$J/\psi(1S)\gamma$			$<$ 2.6	$\times 10^{-6}$	CL=95%	45541
$\psi(2S)X$			(1.60 $\pm$ 0.29)	$\times 10^{-3}$		–
$\chi_{c1}(1P)X$			(2.9 $\pm$ 0.7)	$\times 10^{-3}$		–
$\chi_{c2}(1P)X$			$<$ 3.2	$\times 10^{-3}$	CL=90%	–
$\Upsilon(1S)$ X $+\Upsilon(2S)$ X $+\Upsilon(3S)$ X			(1.0 $\pm$ 0.5)	$\times 10^{-4}$		–
$\Upsilon(1S)X$			$<$ 3.4	$\times 10^{-6}$	CL=95%	–
$\Upsilon(2S)X$			$<$ 6.5	$\times 10^{-6}$	CL=95%	–
$\Upsilon(3S)X$			$<$ 5.4	$\times 10^{-6}$	CL=95%	–
$(D^0/\overline{D}^0)$ X			(20.7 $\pm$ 2.0)	%		–
$D^\pm X$			(12.2 $\pm$ 1.7)	%		–
$D^*(2010)^\pm X$		[j]	(11.4 $\pm$ 1.3)	%		–
$D_{s1}(2536)^\pm X$			(3.6 $\pm$ 0.8)	$\times 10^{-3}$		–
$D_{sJ}(2573)^\pm X$			(5.8 $\pm$ 2.2)	$\times 10^{-3}$		–
B^+X		[k]	(6.08 $\pm$ 0.13)	%		–
B^0_sX		[k]	(1.59 $\pm$ 0.13)	%		–
Λ_c^+X			(1.54 $\pm$ 0.33)	%		–
b-baryon X		[k]	(1.38 $\pm$ 0.22)	%		–
anomalous $\gamma+$ hadrons		[l]	$<$ 3.2	$\times 10^{-3}$	CL=95%	–
$e^+e^-\gamma$		[l]	$<$ 5.2	$\times 10^{-4}$	CL=95%	45594
$\mu^+\mu^-\gamma$		[l]	$<$ 5.6	$\times 10^{-4}$	CL=95%	45594
$\tau^+\tau^-\gamma$		[l]	$<$ 7.3	$\times 10^{-4}$	CL=95%	45559
$\ell^+\ell^-\gamma\gamma$		[n]	$<$ 6.8	$\times 10^{-6}$	CL=95%	–
$q\overline{q}\gamma\gamma$		[n]	$<$ 5.5	$\times 10^{-6}$	CL=95%	–
$\nu\overline{\nu}\gamma\gamma$		[n]	$<$ 3.1	$\times 10^{-6}$	CL=95%	45594
$e^\pm\mu^\mp$	LF	[j]	$<$ 7.5	$\times 10^{-7}$	CL=95%	45594
$e^\pm\tau^\mp$	LF	[j]	$<$ 9.8	$\times 10^{-6}$	CL=95%	45576
$\mu^\pm\tau^\mp$	LF	[j]	$<$ 1.2	$\times 10^{-5}$	CL=95%	45576
pe	L,B		$<$ 1.8	$\times 10^{-6}$	CL=95%	45589
$p\mu$	L,B		$<$ 1.8	$\times 10^{-6}$	CL=95%	45589

See Particle Listings for 4 decay modes that have been seen / not seen.

H^0

$J = 0$

Mass $m = 125.18 \pm 0.16$ GeV
Full width $\Gamma < 0.013$ GeV, CL = 95%

H^0 Signal Strengths in Different Channels

See Listings for the latest unpublished results.

Combined Final States = 1.10 ± 0.11
$W W^* = 1.08^{+0.18}_{-0.16}$
$Z Z^* = 1.14^{+0.15}_{-0.13}$
$\gamma\gamma = 1.16 \pm 0.18$
$b\overline{b} = 0.95 \pm 0.22$
$\mu^+\mu^- = 0.0 \pm 1.3$
$\tau^+\tau^- = 1.12 \pm 0.23$
$Z\gamma <$ 6.6, CL = 95%
$t\overline{t}H^0$ Production $= 2.3^{+0.7}_{-0.6}$

H^0 DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
e^+e^-	$< 1.9 \times 10^{-3}$	95%	62592
$J/\psi\gamma$	$< 1.5 \times 10^{-3}$	95%	62553
$\Upsilon(1S)\gamma$	$< 1.3 \times 10^{-3}$	95%	62234
$\Upsilon(2S)\gamma$	$< 1.9 \times 10^{-3}$	95%	62190
$\Upsilon(3S)\gamma$	$< 1.3 \times 10^{-3}$	95%	62163
$\phi(1020)\gamma$	$< 1.4 \times 10^{-3}$	95%	62587
$e\mu$	$< 3.5 \times 10^{-4}$	95%	62592
$e\tau$	$< 6.9 \times 10^{-3}$	95%	62579
$\mu\tau$	< 1.43 %	95%	62579
invisible	<24 %	95%	–

Neutral Higgs Bosons, Searches for

Searches for a Higgs Boson with Standard Model Couplings

Mass $m >$ 122 and none 128–1000 GeV, CL = 95%

The limits for H^0_1 and A^0 in supersymmetric models refer to the m_h^{max} benchmark scenario for the supersymmetric parameters.

H^0_1 in Supersymmetric Models ($m_{H^0_1} < m_{H^0_2}$)

Mass $m >$ 92.8 GeV, CL = 95%

A^0 Pseudoscalar Higgs Boson in Supersymmetric Models [o]

Mass $m >$ 93.4 GeV, CL = 95% $\tan\beta > 0.4$

Charged Higgs Bosons ($H^\pm$ and $H^{\pm\pm}$), Searches for

$H^\pm$ Mass $m >$ 80 GeV, CL = 95%

New Heavy Bosons (W', Z', leptoquarks, etc.), Searches for

Additional W Bosons

W' with standard couplings

Mass $m >$ 4.100 × 10^3 GeV, CL = 95% ($p\,p$ direct search)

W_R (Right-handed W Boson)

Mass $m >$ 715 GeV, CL = 90% (electroweak fit)

Additional Z Bosons

Z'_{SM} with standard couplings

Mass $m >$ 4.500 × 10^3 GeV, CL = 95% ($p\,p$ direct search)

Z_{LR} of $SU(2)_L \times SU(2)_R \times U(1)$ (with $g_L = g_R$)

Mass $m >$ 630 GeV, CL = 95% ($p\overline{p}$ direct search)

Mass $m >$ 1162 GeV, CL = 95% (electroweak fit)

Z_χ of $SO(10) \rightarrow SU(5) \times U(1)_\chi$ (with $g_\chi = e/\cos\theta_W$)

Mass $m >$ 4.100 × 10^3 GeV, CL = 95% ($p\,p$ direct search)

Z_ψ of $E_6 \rightarrow SO(10) \times U(1)_\psi$ (with $g_\psi = e/\cos\theta_W$)

Mass $m >$ 3.800 × 10^3 GeV, CL = 95% ($p\,p$ direct search)

Z_η of $E_6 \rightarrow SU(3) \times SU(2) \times U(1) \times U(1)_\eta$ (with $g_\eta = e/\cos\theta_W$)

Mass $m >$ 3.900 × 10^3 GeV, CL = 95% ($p\,p$ direct search)

Scalar Leptoquarks

Mass $m >$ 1050 GeV, CL = 95% (1st generation, pair prod.)

Mass $m >$ 1755 GeV, CL = 95% (1st generation, single prod.)

Mass $m >$ 1080 GeV, CL = 95% (2nd generation, pair prod.)

Mass $m >$ 660 GeV, CL = 95% (2nd generation, single prod.)

Mass $m >$ 850 GeV, CL = 95% (3rd generation, pair prod.)

(See the Particle Listings in the Full *Review of Particle Physics* for assumptions on leptoquark quantum numbers and branching fractions.)

Diquarks

Mass $m >$ 6000 GeV, CL = 95% (E_6 diquark)

Axigluon

Mass $m >$ 5500 GeV, CL = 95%

Axions (A^0) and Other Very Light Bosons, Searches for

The standard Peccei-Quinn axion is ruled out. Variants with reduced couplings or much smaller masses are constrained by various data. The Particle Listings in the full *Review* contain a Note discussing axion searches.

The best limit for the half-life of neutrinoless double beta decay with Majoron emission is $> 7.2 \times 10^{24}$ years (CL = 90%).

NOTES

In this Summary Table:

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as $S = \sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame.

[*a*] Theoretical value. A mass as large as a few MeV may not be precluded.

[*b*] ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

[*c*] This represents the width for the decay of the W boson into a charged particle with momentum below detectability, p< 200 MeV.

[*d*] The Z-boson mass listed here corresponds to a Breit-Wigner resonance parameter. It lies approximately 34 MeV above the real part of the position of the pole (in the energy-squared plane) in the Z-boson propagator.

[*e*] This partial width takes into account Z decays into $\nu\overline{\nu}$ and any other possible undetected modes.

[*f*] This ratio has not been corrected for the τ mass.

[*g*] Here $A \equiv 2 g_V g_A/(g_V^2 + g_A^2)$.

[*h*] This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06 (Physics Reports (Physics Letters C) **427** 257 (2006)).

[*i*] Here ℓ indicates e or μ.

[*j*] The value is for the sum of the charge states or particle/antiparticle states indicated.

[*k*] This value is updated using the product of (i) the $Z \rightarrow b\overline{b}$ fraction from this listing and (ii) the b-hadron fraction in an unbiased sample of weakly decaying b-hadrons produced in Z-decays provided by the Heavy Flavor Averaging Group (HFLAV, http://www.slac.stanford.edu/xorg/hflav/osc/PDG_2009/#FRACZ).

[*l*] See the Z Particle Listings in the Full *Review of Particle Physics* for the γ energy range used in this measurement.

[*n*] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.

[*o*] The limits assume no invisible decays.

LEPTONS

e

$J = \frac{1}{2}$

Mass $m = (548.579909070 \pm 0.000000016) \times 10^{-6}$ u
Mass $m = 0.5109989461 \pm 0.0000000031$ MeV
$\left|m_{e^+} - m_{e^-}\right|/m < 8 \times 10^{-9}$, CL = 90%
$\left|q_{e^+} + q_{e^-}\right|/e < 4 \times 10^{-8}$
Magnetic moment anomaly
$(g-2)/2 = (1159.65218091 \pm 0.00000026) \times 10^{-6}$
$(g_{e^+} - g_{e^-}) / g_{\text{average}} = (-0.5 \pm 2.1) \times 10^{-12}$
Electric dipole moment $d < 0.87 \times 10^{-28}$ $e$cm, CL = 90%
Mean life $\tau > 6.6 \times 10^{28}$ yr, CL = 90% [a]

μ

$J = \frac{1}{2}$

Mass $m = 0.1134289257 \pm 0.0000000025$ u
Mass $m = 105.6583745 \pm 0.0000024$ MeV
Mean life $\tau = (2.1969811 \pm 0.0000022) \times 10^{-6}$ s
$\tau_{\mu^+}/\tau_{\mu^-} = 1.00002 \pm 0.00008$
$c\tau = 658.6384$ m
Magnetic moment anomaly $(g-2)/2 = (11659209 \pm 6) \times 10^{-10}$
$(g_{\mu^+} - g_{\mu^-}) / g_{\text{average}} = (-0.11 \pm 0.12) \times 10^{-8}$
Electric dipole moment $d = (-0.1 \pm 0.9) \times 10^{-19}$ $e$cm

Decay parameters [b]

$\rho = 0.74979 \pm 0.00026$
$\eta = 0.057 \pm 0.034$
$\delta = 0.75047 \pm 0.00034$
$\xi P_\mu = 1.0009^{+0.0016}_{-0.0007}$ [c]
$\xi P_\mu \delta/\rho = 1.0018^{+0.0016}_{-0.0007}$ [c]
$\xi' = 1.00 \pm 0.04$
$\xi'' = 0.98 \pm 0.04$
$\alpha/A = (0 \pm 4) \times 10^{-3}$
$\alpha'/A = (-10 \pm 20) \times 10^{-3}$
$\beta/A = (4 \pm 6) \times 10^{-3}$
$\beta'/A = (2 \pm 7) \times 10^{-3}$
$\overline{\eta} = 0.02 \pm 0.08$

μ^+ modes are charge conjugates of the modes below.

μ^- DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$e^- \overline{\nu}_e \nu_\mu$		$\approx 100\%$		53
$e^- \overline{\nu}_e \nu_\mu \gamma$		[d] $(6.0 \pm 0.5) \times 10^{-8}$		53
$e^- \overline{\nu}_e \nu_\mu e^+ e^-$		[e] $(3.4 \pm 0.4) \times 10^{-5}$		53
Lepton Family number (*LF*) violating modes				
$e^- \nu_e \overline{\nu}_\mu$	*LF*	[f] < 1.2 %	90%	53
$e^- \gamma$	*LF*	$< 4.2 \times 10^{-13}$	90%	53
$e^- e^+ e^-$	*LF*	$< 1.0 \times 10^{-12}$	90%	53
$e^- 2\gamma$	*LF*	$< 7.2 \times 10^{-11}$	90%	53

τ

$J = \frac{1}{2}$

Mass $m = 1776.86 \pm 0.12$ MeV
$(m_{\tau^+} - m_{\tau^-})/m_{\text{average}} < 2.8 \times 10^{-4}$, CL = 90%
Mean life $\tau = (290.3 \pm 0.5) \times 10^{-15}$ s
$c\tau = 87.03$ μm
Magnetic moment anomaly > -0.052 and < 0.013, CL = 95%
$\text{Re}(d_\tau) = -0.220$ to 0.45×10^{-16} e cm, CL = 95%
$\text{Im}(d_\tau) = -0.250$ to 0.0080×10^{-16} e cm, CL = 95%

Weak dipole moment

$\text{Re}(d^w_\tau) < 0.50 \times 10^{-17}$ e cm, CL = 95%
$\text{Im}(d^w_\tau) < 1.1 \times 10^{-17}$ e cm, CL = 95%

Weak anomalous magnetic dipole moment

$\text{Re}(\alpha^w_\tau) < 1.1 \times 10^{-3}$, CL = 95%
$\text{Im}(\alpha^w_\tau) < 2.7 \times 10^{-3}$, CL = 95%
$\tau^\pm \to \pi^\pm K^0_S \nu_\tau$ (RATE DIFFERENCE) / (RATE SUM) = $(-0.36 \pm 0.25)\%$

Decay parameters

See the τ Particle Listings in the Full *Review of Particle Physics* for a note concerning τ-decay parameters.

$\rho(e \text{ or } \mu) = 0.745 \pm 0.008$
$\rho(e) = 0.747 \pm 0.010$
$\rho(\mu) = 0.763 \pm 0.020$
$\xi(e \text{ or } \mu) = 0.985 \pm 0.030$
$\xi(e) = 0.994 \pm 0.040$
$\xi(\mu) = 1.030 \pm 0.059$
$\eta(e \text{ or } \mu) = 0.013 \pm 0.020$
$\eta(\mu) = 0.094 \pm 0.073$
$(\delta\xi)(e \text{ or } \mu) = 0.746 \pm 0.021$
$(\delta\xi)(e) = 0.734 \pm 0.028$
$(\delta\xi)(\mu) = 0.778 \pm 0.037$
$\xi(\pi) = 0.993 \pm 0.022$
$\xi(\rho) = 0.994 \pm 0.008$
$\xi(a_1) = 1.001 \pm 0.027$
$\xi(\text{all hadronic modes}) = 0.995 \pm 0.007$
$\overline{\eta}(\mu)$ PARAMETER $= -1.3 \pm 1.7$
$\xi_\kappa(e)$ PARAMETER $= -0.4 \pm 1.2$
$\xi_\kappa(\mu)$ PARAMETER $= 0.8 \pm 0.6$

τ^+ modes are charge conjugates of the modes below. "$h^\pm$" stands for $\pi^\pm$ or $K^\pm$. "ℓ" stands for e or μ. "Neutrals" stands for γ's and/or π^0's.

τ^- DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Modes with one charged particle				
particle$^-$ ≥ 0 neutrals $\geq 0K^0\nu_\tau$ ("1-prong")		(85.24 ± 0.06) %		–
particle$^-$ ≥ 0 neutrals $\geq 0K^0_L\nu_\tau$		(84.58 ± 0.06) %		–
$\mu^-\overline{\nu}_\mu\nu_\tau$	[g]	(17.39 ± 0.04) %		885
$\mu^-\overline{\nu}_\mu\nu_\tau\gamma$	[e]	(3.67 ± 0.08) $\times 10^{-3}$		885
$e^-\overline{\nu}_e\nu_\tau$	[g]	(17.82 ± 0.04) %		888

$e^- \overline{\nu}_e \nu_\tau \gamma$	[e]	(1.83 ± 0.05) %		888
$h^- \geq 0 K_L^0 \; \nu_\tau$		(12.03 ± 0.05) %		883
$h^- \nu_\tau$		(11.51 ± 0.05) %		883
$\pi^- \nu_\tau$	[g]	(10.82 ± 0.05) %		883
$K^- \nu_\tau$	[g]	$(6.96 \pm 0.10) \times 10^{-3}$		820
$h^- \geq 1$ neutrals ν_τ		(37.00 ± 0.09) %		–
$h^- \geq 1\pi^0 \nu_\tau$ (ex.K^0)		(36.51 ± 0.09) %		–
$h^- \pi^0 \nu_\tau$		(25.93 ± 0.09) %		878
$\pi^- \pi^0 \nu_\tau$	[g]	(25.49 ± 0.09) %		878
$\pi^- \pi^0$ non-$\rho(770) \nu_\tau$		$(3.0 \pm 3.2) \times 10^{-3}$		878
$K^- \pi^0 \nu_\tau$	[g]	$(4.33 \pm 0.15) \times 10^{-3}$		814
$h^- \geq 2\pi^0 \nu_\tau$		(10.81 ± 0.09) %		–
$h^- 2\pi^0 \nu_\tau$		(9.48 ± 0.10) %		862
$h^- 2\pi^0 \nu_\tau$ (ex.K^0)		(9.32 ± 0.10) %		862
$\pi^- 2\pi^0 \nu_\tau$ (ex.K^0)	[g]	(9.26 ± 0.10) %		862
$\pi^- 2\pi^0 \nu_\tau$ (ex.K^0), scalar		$< 9 \times 10^{-3}$	CL=95%	862
$\pi^- 2\pi^0 \nu_\tau$ (ex.K^0), vector		$< 7 \times 10^{-3}$	CL=95%	862
$K^- 2\pi^0 \nu_\tau$ (ex.K^0)	[g]	$(6.5 \pm 2.2) \times 10^{-4}$		796
$h^- \geq 3\pi^0 \nu_\tau$		(1.34 ± 0.07) %		–
$h^- \geq 3\pi^0 \nu_\tau$ (ex. K^0)		(1.25 ± 0.07) %		–
$h^- 3\pi^0 \nu_\tau$		(1.18 ± 0.07) %		836
$\pi^- 3\pi^0 \nu_\tau$ (ex.K^0)	[g]	(1.04 ± 0.07) %		836
$K^- 3\pi^0 \nu_\tau$ (ex.K^0, η)	[g]	$(4.8 \pm 2.1) \times 10^{-4}$		765
$h^- 4\pi^0 \nu_\tau$ (ex.K^0)		$(1.6 \pm 0.4) \times 10^{-3}$		800
$h^- 4\pi^0 \nu_\tau$ (ex.K^0,η)	[g]	$(1.1 \pm 0.4) \times 10^{-3}$		800
$a_1(1260) \nu_\tau \to \pi^- \gamma \nu_\tau$		$(3.8 \pm 1.5) \times 10^{-4}$		–
$K^- \geq 0\pi^0 \; \geq 0K^0 \; \geq 0\gamma \; \nu_\tau$		(1.552 ± 0.029) %		820
$K^- \geq 1$ (π^0 or K^0 or γ) ν_τ		$(8.59 \pm 0.28) \times 10^{-3}$		–
Modes with K^0's				
K_S^0 (particles)$^- \nu_\tau$		$(9.44 \pm 0.28) \times 10^{-3}$		–
$h^- \overline{K}^0 \nu_\tau$		$(9.87 \pm 0.14) \times 10^{-3}$		812
$\pi^- \overline{K}^0 \nu_\tau$	[g]	$(8.40 \pm 0.14) \times 10^{-3}$		812
$\pi^- \overline{K}^0$ (non-$K^*(892)^-$) ν_τ		$(5.4 \pm 2.1) \times 10^{-4}$		812
$K^- K^0 \nu_\tau$	[g]	$(1.48 \pm 0.05) \times 10^{-3}$		737
$K^- K^0 \geq 0\pi^0 \nu_\tau$		$(2.98 \pm 0.08) \times 10^{-3}$		737
$h^- \overline{K}^0 \pi^0 \nu_\tau$		$(5.32 \pm 0.13) \times 10^{-3}$		794
$\pi^- \overline{K}^0 \pi^0 \nu_\tau$	[g]	$(3.82 \pm 0.13) \times 10^{-3}$		794
$\overline{K}^0 \rho^- \nu_\tau$		$(2.2 \pm 0.5) \times 10^{-3}$		612
$K^- K^0 \pi^0 \nu_\tau$	[g]	$(1.50 \pm 0.07) \times 10^{-3}$		685
$\pi^- \overline{K}^0 \geq 1\pi^0 \nu_\tau$		$(4.08 \pm 0.25) \times 10^{-3}$		–
$\pi^- \overline{K}^0 \pi^0 \pi^0 \nu_\tau$ (ex.K^0)	[g]	$(2.6 \pm 2.3) \times 10^{-4}$		763
$K^- K^0 \pi^0 \pi^0 \nu_\tau$		$< 1.6 \times 10^{-4}$	CL=95%	619
$\pi^- K^0 \overline{K}^0 \nu_\tau$		$(1.55 \pm 0.24) \times 10^{-3}$		682
$\pi^- K_S^0 K_S^0 \nu_\tau$	[g]	$(2.33 \pm 0.07) \times 10^{-4}$		682
$\pi^- K_S^0 K_L^0 \nu_\tau$	[g]	$(1.08 \pm 0.24) \times 10^{-3}$		682
$\pi^- K_L^0 K_L^0 \nu_\tau$		$(2.33 \pm 0.07) \times 10^{-4}$		682
$\pi^- K^0 \overline{K}^0 \pi^0 \nu_\tau$		$(3.6 \pm 1.2) \times 10^{-4}$		614
$\pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$	[g]	$(1.82 \pm 0.21) \times 10^{-5}$		614
$K^{*-} K^0 \pi^0 \nu_\tau \to \pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$		$(1.08 \pm 0.21) \times 10^{-5}$		–
$f_1(1285) \pi^- \nu_\tau \to \pi^- K_S^0 K_S^0 \pi^0 \nu_\tau$		$(6.8 \pm 1.5) \times 10^{-6}$		–

$f_1(1420)\pi^-\nu_\tau \rightarrow \pi^- K^0_S K^0_S \pi^0 \nu_\tau$		$(2.4 \pm 0.8) \times 10^{-6}$		–
$\pi^- K^0_S K^0_L \pi^0 \nu_\tau$	[g]	$(3.2 \pm 1.2) \times 10^{-4}$		614
$\pi^- K^0_L K^0_L \pi^0 \nu_\tau$		$(1.82 \pm 0.21) \times 10^{-5}$		614
$K^- K^0_S K^0_S \nu_\tau$		$< 6.3 \times 10^{-7}$	CL=90%	466
$K^- K^0_S K^0_S \pi^0 \nu_\tau$		$< 4.0 \times 10^{-7}$	CL=90%	337
$K^0 h^+ h^- h^- \geq 0$ neutrals ν_τ		$< 1.7 \times 10^{-3}$	CL=95%	760
$K^0 h^+ h^- h^- \nu_\tau$	[g]	$(2.5 \pm 2.0) \times 10^{-4}$		760

Modes with three charged particles

$h^- h^- h^+ \geq 0$ neutrals $\geq 0 K^0_L \nu_\tau$		(15.21 ± 0.06) %		861
$h^- h^- h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \rightarrow \pi^+\pi^-$) ("3-prong")		(14.55 ± 0.06) %		861
$h^- h^- h^+ \nu_\tau$		(9.80 ± 0.05) %		861
$h^- h^- h^+ \nu_\tau$ (ex.K^0)		(9.46 ± 0.05) %		861
$h^- h^- h^+ \nu_\tau$ (ex.K^0,ω)		(9.43 ± 0.05) %		861
$\pi^-\pi^+\pi^-\nu_\tau$		(9.31 ± 0.05) %		861
$\pi^-\pi^+\pi^-\nu_\tau$ (ex.K^0)		(9.02 ± 0.05) %		861
$\pi^-\pi^+\pi^-\nu_\tau$ (ex.K^0), non-axial vector		< 2.4 %	CL=95%	861
$\pi^-\pi^+\pi^-\nu_\tau$ (ex.K^0,ω)	[g]	(8.99 ± 0.05) %		861
$h^- h^- h^+ \geq 1$ neutrals ν_τ		(5.29 ± 0.05) %		–
$h^- h^- h^+ \geq 1\pi^0 \nu_\tau$ (ex. K^0)		(5.09 ± 0.05) %		–
$h^- h^- h^+ \pi^0 \nu_\tau$		(4.76 ± 0.05) %		834
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex.K^0)		(4.57 ± 0.05) %		834
$h^- h^- h^+ \pi^0 \nu_\tau$ (ex. K^0, ω)		(2.79 ± 0.07) %		834
$\pi^-\pi^+\pi^-\pi^0\nu_\tau$		(4.62 ± 0.05) %		834
$\pi^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0)		(4.49 ± 0.05) %		834
$\pi^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0,ω)	[g]	(2.74 ± 0.07) %		834
$h^- h^- h^+ \geq 2\pi^0 \nu_\tau$ (ex. K^0)		$(5.17 \pm 0.31) \times 10^{-3}$		–
$h^- h^- h^+ 2\pi^0 \nu_\tau$		$(5.05 \pm 0.31) \times 10^{-3}$		797
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex.K^0)		$(4.95 \pm 0.31) \times 10^{-3}$		797
$h^- h^- h^+ 2\pi^0 \nu_\tau$ (ex.K^0,ω,η)	[g]	$(10 \pm 4) \times 10^{-4}$		797
$h^- h^- h^+ 3\pi^0 \nu_\tau$		$(2.12 \pm 0.30) \times 10^{-4}$		749
$2\pi^-\pi^+ 3\pi^0 \nu_\tau$ (ex.K^0)		$(1.94 \pm 0.30) \times 10^{-4}$		749
$2\pi^-\pi^+ 3\pi^0 \nu_\tau$ (ex.K^0, η, $f_1(1285)$)		$(1.7 \pm 0.4) \times 10^{-4}$		–
$2\pi^-\pi^+ 3\pi^0 \nu_\tau$ (ex.K^0, η, ω, $f_1(1285)$)	[g]	$(1.4 \pm 2.7) \times 10^{-5}$		–
$K^- h^+ h^- \geq 0$ neutrals ν_τ		$(6.29 \pm 0.14) \times 10^{-3}$		794
$K^- h^+ \pi^- \nu_\tau$ (ex.K^0)		$(4.37 \pm 0.07) \times 10^{-3}$		794
$K^- h^+ \pi^- \pi^0 \nu_\tau$ (ex.K^0)		$(8.6 \pm 1.2) \times 10^{-4}$		763
$K^-\pi^+\pi^- \geq 0$ neutrals ν_τ		$(4.77 \pm 0.14) \times 10^{-3}$		794
$K^-\pi^+\pi^- \geq 0\pi^0 \nu_\tau$ (ex.K^0)		$(3.73 \pm 0.13) \times 10^{-3}$		794
$K^-\pi^+\pi^-\nu_\tau$		$(3.45 \pm 0.07) \times 10^{-3}$		794
$K^-\pi^+\pi^-\nu_\tau$ (ex.K^0)		$(2.93 \pm 0.07) \times 10^{-3}$		794
$K^-\pi^+\pi^-\nu_\tau$ (ex.K^0,ω)	[g]	$(2.93 \pm 0.07) \times 10^{-3}$		794
$K^-\rho^0\nu_\tau \rightarrow K^-\pi^+\pi^-\nu_\tau$		$(1.4 \pm 0.5) \times 10^{-3}$		–
$K^-\pi^+\pi^-\pi^0\nu_\tau$		$(1.31 \pm 0.12) \times 10^{-3}$		763
$K^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0)		$(7.9 \pm 1.2) \times 10^{-4}$		763
$K^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0,η)		$(7.6 \pm 1.2) \times 10^{-4}$		763
$K^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0,ω)		$(3.7 \pm 0.9) \times 10^{-4}$		763
$K^-\pi^+\pi^-\pi^0\nu_\tau$ (ex.K^0,ω,η)	[g]	$(3.9 \pm 1.4) \times 10^{-4}$		763
$K^-\pi^+K^- \geq 0$ neut. ν_τ		$< 9 \times 10^{-4}$	CL=95%	685

$K^- K^+ \pi^- \geq 0$ neut. ν_τ		$(1.496 \pm 0.033) \times 10^{-3}$		685
$K^- K^+ \pi^- \nu_\tau$	[g]	$(1.435 \pm 0.027) \times 10^{-3}$		685
$K^- K^+ \pi^- \pi^0 \nu_\tau$	[g]	$(6.1 \pm 1.8) \times 10^{-5}$		618
$K^- K^+ K^- \nu_\tau$		$(2.2 \pm 0.8) \times 10^{-5}$	S=5.4	472
$K^- K^+ K^- \nu_\tau$ (ex. ϕ)		$< 2.5 \times 10^{-6}$	CL=90%	–
$K^- K^+ K^- \pi^0 \nu_\tau$		$< 4.8 \times 10^{-6}$	CL=90%	345
$\pi^- K^+ \pi^- \geq 0$ neut. ν_τ		$< 2.5 \times 10^{-3}$	CL=95%	794
$e^- e^- e^+ \overline{\nu}_e \nu_\tau$		$(2.8 \pm 1.5) \times 10^{-5}$		888
$\mu^- e^- e^+ \overline{\nu}_\mu \nu_\tau$		$< 3.6 \times 10^{-5}$	CL=90%	885
Modes with five charged particles				
$3h^- 2h^+ \geq 0$ neutrals ν_τ (ex. $K^0_S \to \pi^- \pi^+$) ("5-prong")		$(9.9 \pm 0.4) \times 10^{-4}$		794
$3h^- 2h^+ \nu_\tau$ (ex.K^0)		$(8.22 \pm 0.32) \times 10^{-4}$		794
$3\pi^- 2\pi^+ \nu_\tau$ (ex.K^0, ω)		$(8.21 \pm 0.31) \times 10^{-4}$		794
$3\pi^- 2\pi^+ \nu_\tau$ (ex.K^0, ω, $f_1(1285)$)	[g]	$(7.69 \pm 0.30) \times 10^{-4}$		–
$K^- 2\pi^- 2\pi^+ \nu_\tau$ (ex.K^0)	[g]	$(6 \pm 12) \times 10^{-7}$		716
$K^+ 3\pi^- \pi^+ \nu_\tau$		$< 5.0 \times 10^{-6}$	CL=90%	716
$K^+ K^- 2\pi^- \pi^+ \nu_\tau$		$< 4.5 \times 10^{-7}$	CL=90%	528
$3h^- 2h^+ \pi^0 \nu_\tau$ (ex.K^0)		$(1.64 \pm 0.11) \times 10^{-4}$		746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex.K^0)		$(1.62 \pm 0.11) \times 10^{-4}$		746
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex.K^0, η, $f_1(1285)$)		$(1.11 \pm 0.10) \times 10^{-4}$		–
$3\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex.K^0, η, ω, $f_1(1285)$)	[g]	$(3.8 \pm 0.9) \times 10^{-5}$		–
$K^- 2\pi^- 2\pi^+ \pi^0 \nu_\tau$ (ex.K^0)	[g]	$(1.1 \pm 0.6) \times 10^{-6}$		657
$K^+ 3\pi^- \pi^+ \pi^0 \nu_\tau$		$< 8 \times 10^{-7}$	CL=90%	657
$3h^- 2h^+ 2\pi^0 \nu_\tau$		$< 3.4 \times 10^{-6}$	CL=90%	687
Miscellaneous other allowed modes				
$(5\pi)^- \nu_\tau$		$(7.8 \pm 0.5) \times 10^{-3}$		800
$4h^- 3h^+ \geq 0$ neutrals ν_τ ("7-prong")		$< 3.0 \times 10^{-7}$	CL=90%	682
$4h^- 3h^+ \nu_\tau$		$< 4.3 \times 10^{-7}$	CL=90%	682
$4h^- 3h^+ \pi^0 \nu_\tau$		$< 2.5 \times 10^{-7}$	CL=90%	612
$X^- (S{=}-1) \nu_\tau$		(2.92 ± 0.04) %		–
$K^*(892)^- \geq 0$ neutrals $\geq 0 K^0_L \nu_\tau$		(1.42 ± 0.18) %	S=1.4	665
$K^*(892)^- \nu_\tau$		(1.20 ± 0.07) %	S=1.8	665
$K^*(892)^- \nu_\tau \to \pi^- \overline{K}^0 \nu_\tau$		$(7.83 \pm 0.26) \times 10^{-3}$		–
$K^*(892)^0 K^- \geq 0$ neutrals ν_τ		$(3.2 \pm 1.4) \times 10^{-3}$		542
$K^*(892)^0 K^- \nu_\tau$		$(2.1 \pm 0.4) \times 10^{-3}$		542
$\overline{K}^*(892)^0 \pi^- \geq 0$ neutrals ν_τ		$(3.8 \pm 1.7) \times 10^{-3}$		655
$\overline{K}^*(892)^0 \pi^- \nu_\tau$		$(2.2 \pm 0.5) \times 10^{-3}$		655
$(\overline{K}^*(892)\pi)^- \nu_\tau \to \pi^- \overline{K}^0 \pi^0 \nu_\tau$		$(1.0 \pm 0.4) \times 10^{-3}$		–
$K_1(1270)^- \nu_\tau$		$(4.7 \pm 1.1) \times 10^{-3}$		433
$K_1(1400)^- \nu_\tau$		$(1.7 \pm 2.6) \times 10^{-3}$	S=1.7	335
$K^*(1410)^- \nu_\tau$		$(1.5 \,^{+1.4}_{-1.0}) \times 10^{-3}$		320
$K^*_0(1430)^- \nu_\tau$		$< 5 \times 10^{-4}$	CL=95%	317
$K^*_2(1430)^- \nu_\tau$		$< 3 \times 10^{-3}$	CL=95%	317
$\eta \pi^- \nu_\tau$		$< 9.9 \times 10^{-5}$	CL=95%	797
$\eta \pi^- \pi^0 \nu_\tau$	[g]	$(1.39 \pm 0.07) \times 10^{-3}$		778
$\eta \pi^- \pi^0 \pi^0 \nu_\tau$	[g]	$(1.9 \pm 0.4) \times 10^{-4}$		746

$\eta K^- \nu_\tau$	[g]	$(1.55 \pm 0.08) \times 10^{-4}$		719
$\eta K^*(892)^- \nu_\tau$		$(1.38 \pm 0.15) \times 10^{-4}$		511
$\eta K^- \pi^0 \nu_\tau$	[g]	$(4.8 \pm 1.2) \times 10^{-5}$		665
$\eta K^- \pi^0 (\text{non-}K^*(892)) \nu_\tau$		$< 3.5 \times 10^{-5}$	CL=90%	–
$\eta \overline{K}^0 \pi^- \nu_\tau$	[g]	$(9.4 \pm 1.5) \times 10^{-5}$		661
$\eta \overline{K}^0 \pi^- \pi^0 \nu_\tau$		$< 5.0 \times 10^{-5}$	CL=90%	590
$\eta K^- K^0 \nu_\tau$		$< 9.0 \times 10^{-6}$	CL=90%	430
$\eta \pi^+ \pi^- \pi^- \geq 0$ neutrals ν_τ		$< 3 \times 10^{-3}$	CL=90%	744
$\eta \pi^- \pi^+ \pi^- \nu_\tau (\text{ex.}K^0)$	[g]	$(2.19 \pm 0.13) \times 10^{-4}$		744
$\eta \pi^- \pi^+ \pi^- \nu_\tau (\text{ex.}K^0, f_1(1285))$		$(9.9 \pm 1.6) \times 10^{-5}$		–
$\eta a_1(1260)^- \nu_\tau \to \eta \pi^- \rho^0 \nu_\tau$		$< 3.9 \times 10^{-4}$	CL=90%	–
$\eta \eta \pi^- \nu_\tau$		$< 7.4 \times 10^{-6}$	CL=90%	637
$\eta \eta \pi^- \pi^0 \nu_\tau$		$< 2.0 \times 10^{-4}$	CL=95%	559
$\eta \eta K^- \nu_\tau$		$< 3.0 \times 10^{-6}$	CL=90%	382
$\eta'(958) \pi^- \nu_\tau$		$< 4.0 \times 10^{-6}$	CL=90%	620
$\eta'(958) \pi^- \pi^0 \nu_\tau$		$< 1.2 \times 10^{-5}$	CL=90%	591
$\eta'(958) K^- \nu_\tau$		$< 2.4 \times 10^{-6}$	CL=90%	495
$\phi \pi^- \nu_\tau$		$(3.4 \pm 0.6) \times 10^{-5}$		585
$\phi K^- \nu_\tau$	[g]	$(4.4 \pm 1.6) \times 10^{-5}$		445
$f_1(1285) \pi^- \nu_\tau$		$(3.9 \pm 0.5) \times 10^{-4}$	S=1.9	408
$f_1(1285) \pi^- \nu_\tau \to \eta \pi^- \pi^+ \pi^- \nu_\tau$		$(1.18 \pm 0.07) \times 10^{-4}$	S=1.3	–
$f_1(1285) \pi^- \nu_\tau \to 3\pi^- 2\pi^+ \nu_\tau$	[g]	$(5.2 \pm 0.4) \times 10^{-5}$		–
$\pi(1300)^- \nu_\tau \to (\rho \pi)^- \nu_\tau \to (3\pi)^- \nu_\tau$		$< 1.0 \times 10^{-4}$	CL=90%	–
$\pi(1300)^- \nu_\tau \to ((\pi\pi)_{S-\text{wave}} \pi)^- \nu_\tau \to (3\pi)^- \nu_\tau$		$< 1.9 \times 10^{-4}$	CL=90%	–
$h^- \omega \geq 0$ neutrals ν_τ		(2.40 ± 0.08) %		708
$h^- \omega \nu_\tau$		(1.99 ± 0.06) %		708
$\pi^- \omega \nu_\tau$	[g]	(1.95 ± 0.06) %		708
$K^- \omega \nu_\tau$	[g]	$(4.1 \pm 0.9) \times 10^{-4}$		610
$h^- \omega \pi^0 \nu_\tau$	[g]	$(4.1 \pm 0.4) \times 10^{-3}$		684
$h^- \omega 2\pi^0 \nu_\tau$		$(1.4 \pm 0.5) \times 10^{-4}$		644
$\pi^- \omega 2\pi^0 \nu_\tau$	[g]	$(7.1 \pm 1.6) \times 10^{-5}$		644
$h^- 2\omega \nu_\tau$		$< 5.4 \times 10^{-7}$	CL=90%	250
$2h^- h^+ \omega \nu_\tau$		$(1.20 \pm 0.22) \times 10^{-4}$		641
$2\pi^- \pi^+ \omega \nu_\tau (\text{ex.}K^0)$	[g]	$(8.4 \pm 0.6) \times 10^{-5}$		641

Lepton Family number (*LF*), Lepton number (*L*), or Baryon number (*B*) violating modes

L means lepton number violation (*e.g.* $\tau^- \to e^+ \pi^- \pi^-$). Following common usage, *LF* means lepton family violation *and not* lepton number violation (*e.g.* $\tau^- \to e^- \pi^+ \pi^-$). *B* means baryon number violation.

$e^- \gamma$	*LF*	$< 3.3 \times 10^{-8}$	CL=90%	888
$\mu^- \gamma$	*LF*	$< 4.4 \times 10^{-8}$	CL=90%	885
$e^- \pi^0$	*LF*	$< 8.0 \times 10^{-8}$	CL=90%	883
$\mu^- \pi^0$	*LF*	$< 1.1 \times 10^{-7}$	CL=90%	880
$e^- K_S^0$	*LF*	$< 2.6 \times 10^{-8}$	CL=90%	819
$\mu^- K_S^0$	*LF*	$< 2.3 \times 10^{-8}$	CL=90%	815
$e^- \eta$	*LF*	$< 9.2 \times 10^{-8}$	CL=90%	804
$\mu^- \eta$	*LF*	$< 6.5 \times 10^{-8}$	CL=90%	800
$e^- \rho^0$	*LF*	$< 1.8 \times 10^{-8}$	CL=90%	719
$\mu^- \rho^0$	*LF*	$< 1.2 \times 10^{-8}$	CL=90%	715
$e^- \omega$	*LF*	$< 4.8 \times 10^{-8}$	CL=90%	716

$\mu^- \omega$	*LF*	$<$	4.7	$\times 10^{-8}$	CL=90%	711
$e^- K^*(892)^0$	*LF*	$<$	3.2	$\times 10^{-8}$	CL=90%	665
$\mu^- K^*(892)^0$	*LF*	$<$	5.9	$\times 10^{-8}$	CL=90%	659
$e^- \overline{K}^*(892)^0$	*LF*	$<$	3.4	$\times 10^{-8}$	CL=90%	665
$\mu^- \overline{K}^*(892)^0$	*LF*	$<$	7.0	$\times 10^{-8}$	CL=90%	659
$e^- \eta'(958)$	*LF*	$<$	1.6	$\times 10^{-7}$	CL=90%	630
$\mu^- \eta'(958)$	*LF*	$<$	1.3	$\times 10^{-7}$	CL=90%	625
$e^- f_0(980) \rightarrow e^- \pi^+ \pi^-$	*LF*	$<$	3.2	$\times 10^{-8}$	CL=90%	–
$\mu^- f_0(980) \rightarrow \mu^- \pi^+ \pi^-$	*LF*	$<$	3.4	$\times 10^{-8}$	CL=90%	–
$e^- \phi$	*LF*	$<$	3.1	$\times 10^{-8}$	CL=90%	596
$\mu^- \phi$	*LF*	$<$	8.4	$\times 10^{-8}$	CL=90%	590
$e^- e^+ e^-$	*LF*	$<$	2.7	$\times 10^{-8}$	CL=90%	888
$e^- \mu^+ \mu^-$	*LF*	$<$	2.7	$\times 10^{-8}$	CL=90%	882
$e^+ \mu^- \mu^-$	*LF*	$<$	1.7	$\times 10^{-8}$	CL=90%	882
$\mu^- e^+ e^-$	*LF*	$<$	1.8	$\times 10^{-8}$	CL=90%	885
$\mu^+ e^- e^-$	*LF*	$<$	1.5	$\times 10^{-8}$	CL=90%	885
$\mu^- \mu^+ \mu^-$	*LF*	$<$	2.1	$\times 10^{-8}$	CL=90%	873
$e^- \pi^+ \pi^-$	*LF*	$<$	2.3	$\times 10^{-8}$	CL=90%	877
$e^+ \pi^- \pi^-$	*L*	$<$	2.0	$\times 10^{-8}$	CL=90%	877
$\mu^- \pi^+ \pi^-$	*LF*	$<$	2.1	$\times 10^{-8}$	CL=90%	866
$\mu^+ \pi^- \pi^-$	*L*	$<$	3.9	$\times 10^{-8}$	CL=90%	866
$e^- \pi^+ K^-$	*LF*	$<$	3.7	$\times 10^{-8}$	CL=90%	813
$e^- \pi^- K^+$	*LF*	$<$	3.1	$\times 10^{-8}$	CL=90%	813
$e^+ \pi^- K^-$	*L*	$<$	3.2	$\times 10^{-8}$	CL=90%	813
$e^- K^0_S K^0_S$	*LF*	$<$	7.1	$\times 10^{-8}$	CL=90%	736
$e^- K^+ K^-$	*LF*	$<$	3.4	$\times 10^{-8}$	CL=90%	738
$e^+ K^- K^-$	*L*	$<$	3.3	$\times 10^{-8}$	CL=90%	738
$\mu^- \pi^+ K^-$	*LF*	$<$	8.6	$\times 10^{-8}$	CL=90%	800
$\mu^- \pi^- K^+$	*LF*	$<$	4.5	$\times 10^{-8}$	CL=90%	800
$\mu^+ \pi^- K^-$	*L*	$<$	4.8	$\times 10^{-8}$	CL=90%	800
$\mu^- K^0_S K^0_S$	*LF*	$<$	8.0	$\times 10^{-8}$	CL=90%	696
$\mu^- K^+ K^-$	*LF*	$<$	4.4	$\times 10^{-8}$	CL=90%	699
$\mu^+ K^- K^-$	*L*	$<$	4.7	$\times 10^{-8}$	CL=90%	699
$e^- \pi^0 \pi^0$	*LF*	$<$	6.5	$\times 10^{-6}$	CL=90%	878
$\mu^- \pi^0 \pi^0$	*LF*	$<$	1.4	$\times 10^{-5}$	CL=90%	867
$e^- \eta\eta$	*LF*	$<$	3.5	$\times 10^{-5}$	CL=90%	699
$\mu^- \eta\eta$	*LF*	$<$	6.0	$\times 10^{-5}$	CL=90%	653
$e^- \pi^0 \eta$	*LF*	$<$	2.4	$\times 10^{-5}$	CL=90%	798
$\mu^- \pi^0 \eta$	*LF*	$<$	2.2	$\times 10^{-5}$	CL=90%	784
$p \mu^- \mu^-$	*L,B*	$<$	4.4	$\times 10^{-7}$	CL=90%	618
$\overline{p} \mu^+ \mu^-$	*L,B*	$<$	3.3	$\times 10^{-7}$	CL=90%	618
$\overline{p} \gamma$	*L,B*	$<$	3.5	$\times 10^{-6}$	CL=90%	641
$\overline{p} \pi^0$	*L,B*	$<$	1.5	$\times 10^{-5}$	CL=90%	632
$\overline{p} 2\pi^0$	*L,B*	$<$	3.3	$\times 10^{-5}$	CL=90%	604
$\overline{p} \eta$	*L,B*	$<$	8.9	$\times 10^{-6}$	CL=90%	475
$\overline{p} \pi^0 \eta$	*L,B*	$<$	2.7	$\times 10^{-5}$	CL=90%	360
$\Lambda \pi^-$	*L,B*	$<$	7.2	$\times 10^{-8}$	CL=90%	525
$\overline{\Lambda} \pi^-$	*L,B*	$<$	1.4	$\times 10^{-7}$	CL=90%	525
e^- light boson	*LF*	$<$	2.7	$\times 10^{-3}$	CL=95%	–
μ^- light boson	*LF*	$<$	5	$\times 10^{-3}$	CL=95%	–

Heavy Charged Lepton Searches

$L^{\pm}$ – charged lepton

Mass $m >$ 100.8 GeV, CL = 95% [h] Decay to νW.

$L^{\pm}$ – stable charged heavy lepton

Mass $m >$ 102.6 GeV, CL = 95%

Neutrino Properties

See the note on "Neutrino properties listings" in the Particle Listings.

Mass $m <$ 2 eV (tritium decay)
Mean life/mass, $\tau/m >$ 300 s/eV, CL = 90% (reactor)
Mean life/mass, $\tau/m >$ 7×10^9 s/eV (solar)
Mean life/mass, $\tau/m >$ 15.4 s/eV, CL = 90% (accelerator)
Magnetic moment μ < 0.29×10^{-10} μ_B, CL = 90% (reactor)

Number of Neutrino Types

Number $N = 2.984 \pm 0.008$ (Standard Model fits to LEP-SLC data)
Number $N = 2.92 \pm 0.05$ (S = 1.2) (Direct measurement of invisible Z width)

Neutrino Mixing

The following values are obtained through data analyses based on the 3-neutrino mixing scheme described in the review "Neutrino Mass, Mixing, and Oscillations" by K. Nakamura and S.T. Petcov in this *Review*.

$\sin^2(\theta_{12}) = 0.307 \pm 0.013$
$\Delta m^2_{21} = (7.53 \pm 0.18) \times 10^{-5}$ eV^2
$\sin^2(\theta_{23}) = 0.421^{+0.033}_{-0.025}$ (S = 1.3) (Inverted order, quad. I)
$\sin^2(\theta_{23}) = 0.592^{+0.023}_{-0.030}$ (S = 1.1) (Inverted order, quad. II)
$\sin^2(\theta_{23}) = 0.417^{+0.025}_{-0.028}$ (S = 1.2) (Normal order, quad. I)
$\sin^2(\theta_{23}) = 0.597^{+0.024}_{-0.030}$ (S = 1.2) (Normal order, quad. II)
$\Delta m^2_{32} = (-2.56 \pm 0.04) \times 10^{-3}$ eV^2 (Inverted order)
$\Delta m^2_{32} = (2.51 \pm 0.05) \times 10^{-3}$ eV^2 (S = 1.1) (Normal order)
$\sin^2(\theta_{13}) = (2.12 \pm 0.08) \times 10^{-2}$

Stable Neutral Heavy Lepton Mass Limits

Mass $m >$ 45.0 GeV, CL = 95% (Dirac)
Mass $m >$ 39.5 GeV, CL = 95% (Majorana)

Neutral Heavy Lepton Mass Limits

Mass $m >$ 90.3 GeV, CL = 95%
(Dirac ν_L coupling to e, μ, τ; conservative case(τ))
Mass $m >$ 80.5 GeV, CL = 95%
(Majorana ν_L coupling to e, μ, τ; conservative case(τ))

NOTES

In this Summary Table:

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as $S = \sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame.

[*a*] This is the best limit for the mode $e^- \rightarrow \nu\gamma$. The best limit for "electron disappearance" is 6.4×10^{24} yr.

[*b*] See the "Note on Muon Decay Parameters" in the μ Particle Listings in the Full *Review of Particle Physics* for definitions and details.

[*c*] P_μ is the longitudinal polarization of the muon from pion decay. In standard $V-A$ theory, $P_\mu = 1$ and $\rho = \delta = 3/4$.

[*d*] This only includes events with energy of $e > 45$ MeV and energy of $\gamma > 40$ MeV. Since the $e^- \overline{\nu}_e \nu_\mu$ and $e^- \overline{\nu}_e \nu_\mu \gamma$ modes cannot be clearly separated, we regard the latter mode as a subset of the former.

[*e*] See the relevant Particle Listings in the Full *Review of Particle Physics* for the energy limits used in this measurement.

[*f*] A test of additive vs. multiplicative lepton family number conservation.

[*g*] Basis mode for the τ.

[*h*] $L^\pm$ mass limit depends on decay assumptions; see the Full Listings.

QUARKS

The u-, d-, and s-quark masses are estimates of so-called "current-quark masses," in a mass-independent subtraction scheme such as $\overline{\mathrm{MS}}$ at a scale $\mu \approx 2$ GeV. The c- and b-quark masses are the "running" masses in the $\overline{\mathrm{MS}}$ scheme. This can be different from the heavy quark masses obtained in potential models.

u

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

$m_u = 2.2^{+0.5}_{-0.4}$ MeV Charge $= \frac{2}{3}\ e$ $I_z = +\frac{1}{2}$

$m_u/m_d = 0.48^{+0.07}_{-0.08}$

d

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

$m_d = 4.7^{+0.5}_{-0.3}$ MeV Charge $= -\frac{1}{3}\ e$ $I_z = -\frac{1}{2}$

$m_s/m_d = 17\text{–}22$

$\overline{m} = (m_u+m_d)/2 = 3.5^{+0.5}_{-0.2}$ MeV

s

$I(J^P) = 0(\frac{1}{2}^+)$

$m_s = 95^{+9}_{-3}$ MeV Charge $= -\frac{1}{3}\ e$ Strangeness $= -1$

$m_s \ / \ ((m_u + m_d)/2) = 27.3 \pm 0.7$

c

$I(J^P) = 0(\frac{1}{2}^+)$

$m_c = 1.275^{+0.025}_{-0.035}$ GeV Charge $= \frac{2}{3}\ e$ Charm $= +1$

$m_c/m_s = 11.72 \pm 0.25$

$m_b/m_c = 4.53 \pm 0.05$

$m_b - m_c = 3.45 \pm 0.05$ GeV

b

$I(J^P) = 0(\frac{1}{2}^+)$

$m_b = 4.18^{+0.04}_{-0.03}$ GeV Charge $= -\frac{1}{3}\ e$ Bottom $= -1$

t

$I(J^P) = 0(\frac{1}{2}^+)$

Charge $= \frac{2}{3}\ e$ Top $= +1$

Mass (direct measurements) $m = 173.0 \pm 0.4$ GeV [a,b] (S = 1.3)

Mass (from cross-section measurements) $m = 160^{+5}_{-4}$ GeV [a]

Mass (Pole from cross-section measurements) $m = 173.1 \pm 0.9$ GeV

$m_t - m_{\overline{t}} = -0.16 \pm 0.19$ GeV

Full width $\Gamma = 1.41^{+0.19}_{-0.15}$ GeV (S = 1.4)

$\Gamma(W b)/\Gamma(W q(q = b,\ s,\ d)) = 0.957 \pm 0.034$ (S = 1.5)

t-quark EW Couplings

$F_0 = 0.687 \pm 0.018$
$F_- = 0.320 \pm 0.013$
$F_+ = 0.002 \pm 0.011$
$F_{V+A} < 0.29$, CL = 95%

t DECAY MODES		Fraction (Γ_i/Γ)		Confidence level	p (MeV/c)
$t \to Wq(q = b, s, d)$					–
$t \to Wb$					–
$t \to e\nu_e b$		(13.3 ± 0.6) %			–
$t \to \mu\nu_\mu b$		(13.4 ± 0.6) %			–
$t \to \tau\nu_\tau b$		(7.1 ± 0.6) %			–
$t \to q\overline{q}b$		(66.5 ± 1.4) %			–
$\Delta T = 1$ weak neutral current (*T1*) modes					
$t \to Zq(q{=}u,c)$	*T1*	[c] < 5	$\times 10^{-4}$	95%	–
$t \to Hu$	*T1*	< 2.4	$\times 10^{-3}$	95%	–
$t \to Hc$	*T1*	< 2.2	$\times 10^{-3}$	95%	–
$t \to \ell^+\overline{q}\overline{q}'(q{=}d,s,b;$ $q'{=}u,c)$	*T1*	< 1.6	$\times 10^{-3}$	95%	–

b' (4th Generation) Quark, Searches for

Mass $m >$ 190 GeV, CL = 95% ($p\overline{p}$, quasi-stable b')
Mass $m >$ 755 GeV, CL = 95% (pp, neutral-current decays)
Mass $m >$ 880 GeV, CL = 95% (pp, charged-current decays)
Mass $m >$ 46.0 GeV, CL = 95% (e^+e^-, all decays)

t' (4th Generation) Quark, Searches for

$m(t'(2/3)) >$ 1160 GeV, CL = 95% (neutral-current decays)
$m(t'(2/3)) >$ 770 GeV, CL = 95% (charged-current decays)
$m(t'(5/3)) >$ 990 GeV, CL = 95%

Free Quark Searches

All searches since 1977 have had negative results.

NOTES

[*a*] A discussion of the definition of the top quark mass in these measurements can be found in the review "The Top Quark."

[*b*] Based on published top mass measurements using data from Tevatron Run-I and Run-II and LHC at $\sqrt{s} = 7$ TeV. Including the most recent unpublished results from Tevatron Run-II, the Tevatron Electroweak Working Group reports a top mass of 173.2 ± 0.9 GeV. See the note "The Top Quark' in the Quark Particle Listings of this *Review*.

[*c*] This limit is for $\Gamma(t \to Zq)/\Gamma(t \to Wb)$.

LIGHT UNFLAVORED MESONS
($S = C = B = 0$)

For $I = 1$ (π, b, ρ, a): $u\overline{d}$, $(u\overline{u}-d\overline{d})/\sqrt{2}$, $d\overline{u}$;
for $I = 0$ (η, η', h, h', ω, ϕ, f, f'): $c_1(u\overline{u} + d\overline{d}) + c_2(s\overline{s})$

$\pi^\pm$

$I^G(J^P) = 1^-(0^-)$

Mass $m = 139.57061 \pm 0.00024$ MeV (S = 1.6)
Mean life $\tau = (2.6033 \pm 0.0005) \times 10^{-8}$ s (S = 1.2)
$c\tau = 7.8045$ m

$\pi^\pm \rightarrow \ell^\pm \nu\gamma$ form factors [a]

$F_V = 0.0254 \pm 0.0017$
$F_A = 0.0119 \pm 0.0001$
F_V slope parameter $a = 0.10 \pm 0.06$
$R = 0.059^{+0.009}_{-0.008}$

π^- modes are charge conjugates of the modes below.

For decay limits to particles which are not established, see the section on Searches for Axions and Other Very Light Bosons.

π^+ DECAY MODES			Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\mu^+\nu_\mu$		[b]	(99.98770 ± 0.00004) %		30
$\mu^+\nu_\mu\gamma$		[c]	$(2.00 \pm 0.25) \times 10^{-4}$		30
$e^+\nu_e$		[b]	$(1.230 \pm 0.004) \times 10^{-4}$		70
$e^+\nu_e\gamma$		[c]	$(7.39 \pm 0.05) \times 10^{-7}$		70
$e^+\nu_e\pi^0$			$(1.036 \pm 0.006) \times 10^{-8}$		4
$e^+\nu_e e^+e^-$			$(3.2 \pm 0.5) \times 10^{-9}$		70
$e^+\nu_e\nu\overline{\nu}$			$< 5 \times 10^{-6}$	90%	70
Lepton Family number (*LF*) or Lepton number (*L*) violating modes					
$\mu^+\overline{\nu}_e$	*L*	[d]	$< 1.5 \times 10^{-3}$	90%	30
$\mu^+\nu_e$	*LF*	[d]	$< 8.0 \times 10^{-3}$	90%	30
$\mu^-e^+e^+\nu$	*LF*		$< 1.6 \times 10^{-6}$	90%	30

π^0

$I^G(J^{PC}) = 1^-(0^{-+})$

Mass $m = 134.9770 \pm 0.0005$ MeV (S = 1.1)
$m_{\pi^\pm} - m_{\pi^0} = 4.5936 \pm 0.0005$ MeV
Mean life $\tau = (8.52 \pm 0.18) \times 10^{-17}$ s (S = 1.2)
$c\tau = 25.5$ nm

For decay limits to particles which are not established, see the appropriate Search sections (A^0 (axion) and Other Light Boson (X^0) Searches, etc.).

π^0 DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
2γ	(98.823 ± 0.034) %	S=1.5	67
$e^+e^-\gamma$	(1.174 ± 0.035) %	S=1.5	67
γ positronium	$(1.82 \pm 0.29) \times 10^{-9}$		67
$e^+e^+e^-e^-$	$(3.34 \pm 0.16) \times 10^{-5}$		67

$e^+ e^-$			$(6.46 \pm 0.33) \times 10^{-8}$		67
4γ		$<$	2×10^{-8}	CL=90%	67
$\nu\overline{\nu}$		[e] $<$	2.7×10^{-7}	CL=90%	67
$\nu_e \overline{\nu}_e$		$<$	1.7×10^{-6}	CL=90%	67
$\nu_\mu \overline{\nu}_\mu$		$<$	1.6×10^{-6}	CL=90%	67
$\nu_\tau \overline{\nu}_\tau$		$<$	2.1×10^{-6}	CL=90%	67
$\gamma \nu \overline{\nu}$		$<$	6×10^{-4}	CL=90%	67
Charge conjugation (*C*) or Lepton Family number (*LF*) violating modes					
3γ	*C*	$<$	3.1×10^{-8}	CL=90%	67
$\mu^+ e^-$	*LF*	$<$	3.8×10^{-10}	CL=90%	26
$\mu^- e^+$	*LF*	$<$	3.4×10^{-9}	CL=90%	26
$\mu^+ e^- + \mu^- e^+$	*LF*	$<$	3.6×10^{-10}	CL=90%	26

η

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 547.862 \pm 0.017$ MeV
Full width $\Gamma = 1.31 \pm 0.05$ keV

C-nonconserving decay parameters

$\pi^+\pi^-\pi^0$ left-right asymmetry $= (0.09^{+0.11}_{-0.12}) \times 10^{-2}$
$\pi^+\pi^-\pi^0$ sextant asymmetry $= (0.12^{+0.10}_{-0.11}) \times 10^{-2}$
$\pi^+\pi^-\pi^0$ quadrant asymmetry $= (-0.09 \pm 0.09) \times 10^{-2}$
$\pi^+\pi^-\gamma$ left-right asymmetry $= (0.9 \pm 0.4) \times 10^{-2}$
$\pi^+\pi^-\gamma$ β (*D*-wave) $= -0.02 \pm 0.07$ (S = 1.3)

CP-nonconserving decay parameters

$\pi^+\pi^- e^+ e^-$ decay-plane asymmetry $A_\phi = (-0.6 \pm 3.1) \times 10^{-2}$

Dalitz plot parameter

$\pi^0\pi^0\pi^0$ $\alpha = -0.0318 \pm 0.0015$
Parameter Λ in $\eta \to \ell^+\ell^-\gamma$ decay $= 0.716 \pm 0.011$ GeV/c^2

η DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Neutral modes				
neutral modes		(72.12 ± 0.34) %	S=1.2	–
2γ		(39.41 ± 0.20) %	S=1.1	274
$3\pi^0$		(32.68 ± 0.23) %	S=1.1	179
$\pi^0 2\gamma$		$(2.56 \pm 0.22) \times 10^{-4}$		257
$2\pi^0 2\gamma$	$<$	1.2×10^{-3}	CL=90%	238
4γ	$<$	2.8×10^{-4}	CL=90%	274
invisible	$<$	1.0×10^{-4}	CL=90%	–
Charged modes				
charged modes		(28.10 ± 0.34) %	S=1.2	–
$\pi^+\pi^-\pi^0$		(22.92 ± 0.28) %	S=1.2	174
$\pi^+\pi^-\gamma$		(4.22 ± 0.08) %	S=1.1	236
$e^+ e^- \gamma$		$(6.9 \pm 0.4) \times 10^{-3}$	S=1.3	274
$\mu^+\mu^-\gamma$		$(3.1 \pm 0.4) \times 10^{-4}$		253
$e^+ e^-$	$<$	2.3×10^{-6}	CL=90%	274
$\mu^+\mu^-$		$(5.8 \pm 0.8) \times 10^{-6}$		253
$2e^+ 2e^-$		$(2.40 \pm 0.22) \times 10^{-5}$		274
$\pi^+\pi^- e^+ e^- (\gamma)$		$(2.68 \pm 0.11) \times 10^{-4}$		235
$e^+ e^- \mu^+ \mu^-$	$<$	1.6×10^{-4}	CL=90%	253
$2\mu^+ 2\mu^-$	$<$	3.6×10^{-4}	CL=90%	161

$\mu^+\mu^-\pi^+\pi^-$			$<$ 3.6	$\times 10^{-4}$	CL=90%	113
$\pi^+e^-\overline{\nu}_e$ + c.c.			$<$ 1.7	$\times 10^{-4}$	CL=90%	256
$\pi^+\pi^-2\gamma$			$<$ 2.1	$\times 10^{-3}$		236
$\pi^+\pi^-\pi^0\gamma$			$<$ 5	$\times 10^{-4}$	CL=90%	174
$\pi^0\mu^+\mu^-\gamma$			$<$ 3	$\times 10^{-6}$	CL=90%	210
Charge conjugation (C), Parity (P), Charge conjugation × Parity (CP), or Lepton Family number (LF) violating modes						
$\pi^0\gamma$	C		$<$ 9	$\times 10^{-5}$	CL=90%	257
$\pi^+\pi^-$	P,CP		$<$ 1.3	$\times 10^{-5}$	CL=90%	236
$2\pi^0$	P,CP		$<$ 3.5	$\times 10^{-4}$	CL=90%	238
$2\pi^0\gamma$	C		$<$ 5	$\times 10^{-4}$	CL=90%	238
$3\pi^0\gamma$	C		$<$ 6	$\times 10^{-5}$	CL=90%	179
3γ	C		$<$ 1.6	$\times 10^{-5}$	CL=90%	274
$4\pi^0$	P,CP		$<$ 6.9	$\times 10^{-7}$	CL=90%	40
$\pi^0e^+e^-$	C	[f]	$<$ 4	$\times 10^{-5}$	CL=90%	257
$\pi^0\mu^+\mu^-$	C	[f]	$<$ 5	$\times 10^{-6}$	CL=90%	210
μ^+e^- + μ^-e^+	LF		$<$ 6	$\times 10^{-6}$	CL=90%	264

$f_0(500)$ [g]

$I^G(J^{PC}) = 0^+(0^{++})$

Mass (T-Matrix Pole $\sqrt{s}$) = (400–550)$-i$(200–350) MeV
Mass (Breit-Wigner) = (400–550) MeV
Full width (Breit-Wigner) = (400–700) MeV

f_0(500) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	dominant	–

See Particle Listings for 1 decay modes that have been seen / not seen.

$\rho(770)$ [h]

$I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 775.26 \pm 0.25$ MeV
Full width $\Gamma = 149.1 \pm 0.8$ MeV
$\Gamma_{ee} = 7.04 \pm 0.06$ keV

ρ(770) DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi\pi$		$\sim$ 100 %		363
$\rho(770)^\pm$ decays				
$\pi^\pm\gamma$		(4.5 $\pm$0.5) $\times 10^{-4}$	S=2.2	375
$\pi^\pm\eta$		$<$ 6 $\times 10^{-3}$	CL=84%	152
$\pi^\pm\pi^+\pi^-\pi^0$		$<$ 2.0 $\times 10^{-3}$	CL=84%	254
$\rho(770)^0$ decays				
$\pi^+\pi^-\gamma$		(9.9 $\pm$1.6) $\times 10^{-3}$		362
$\pi^0\gamma$		(4.7 $\pm$0.6) $\times 10^{-4}$	S=1.4	376
$\eta\gamma$		(3.00$\pm$0.21) $\times 10^{-4}$		194
$\pi^0\pi^0\gamma$		(4.5 $\pm$0.8) $\times 10^{-5}$		363
$\mu^+\mu^-$	[i]	(4.55$\pm$0.28) $\times 10^{-5}$		373
e^+e^-	[i]	(4.72$\pm$0.05) $\times 10^{-5}$		388
$\pi^+\pi^-\pi^0$		($1.01^{+0.54}_{-0.36}$$\pm$0.34) $\times 10^{-4}$		323
$\pi^+\pi^-\pi^+\pi^-$		(1.8 $\pm$0.9) $\times 10^{-5}$		251

$\pi^+\pi^-\pi^0\pi^0$	$(1.6\ \pm0.8\ )\times10^{-5}$			257
$\pi^0 e^+ e^-$	$< 1.2\ \times10^{-5}$		CL=90%	376

$\omega(782)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 782.65 \pm 0.12$ MeV (S = 1.9)
Full width $\Gamma = 8.49 \pm 0.08$ MeV
$\Gamma_{ee} = 0.60 \pm 0.02$ keV

$\omega(782)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi^+\pi^-\pi^0$		$(89.2\ \pm0.7\ )\ \%$		327
$\pi^0\gamma$		$(\ 8.40\pm0.22)\ \%$	S=1.8	380
$\pi^+\pi^-$		$(\ 1.53^{+0.11}_{-0.13})\ \%$	S=1.2	366
neutrals (excluding $\pi^0\gamma$)		$(\ 7\ ^{+7}_{-4}\ )\times10^{-3}$	S=1.1	–
$\eta\gamma$		$(\ 4.5\ \pm0.4\ )\times10^{-4}$	S=1.1	200
$\pi^0 e^+ e^-$		$(\ 7.7\ \pm0.6\ )\times10^{-4}$		380
$\pi^0\mu^+\mu^-$		$(\ 1.34\pm0.18)\times10^{-4}$	S=1.5	349
e^+e^-		$(\ 7.36\pm0.15)\times10^{-5}$	S=1.5	391
$\pi^+\pi^-\pi^0\pi^0$		$< 2\ \times10^{-4}$	CL=90%	262
$\pi^+\pi^-\gamma$		$< 3.6\ \times10^{-3}$	CL=95%	366
$\pi^+\pi^-\pi^+\pi^-$		$< 1\ \times10^{-3}$	CL=90%	256
$\pi^0\pi^0\gamma$		$(\ 6.7\ \pm1.1\ )\times10^{-5}$		367
$\eta\pi^0\gamma$		$< 3.3\ \times10^{-5}$	CL=90%	162
$\mu^+\mu^-$		$(\ 7.4\ \pm1.8\ )\times10^{-5}$		377
3γ		$< 1.9\ \times10^{-4}$	CL=95%	391
Charge conjugation (C) violating modes				
$\eta\pi^0$	C	$< 2.2\ \times10^{-4}$	CL=90%	162
$2\pi^0$	C	$< 2.2\ \times10^{-4}$	CL=90%	367
$3\pi^0$	C	$< 2.3\ \times10^{-4}$	CL=90%	330

$\eta'(958)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 957.78 \pm 0.06$ MeV
Full width $\Gamma = 0.196 \pm 0.009$ MeV

$\eta'(958)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\pi^+\pi^-\eta$	$(42.6\ \pm0.7\ )\ \%$		232
$\rho^0\gamma$ (including non-resonant $\pi^+\pi^-\gamma$)	$(28.9\ \pm0.5\ )\ \%$		165
$\pi^0\pi^0\eta$	$(22.8\ \pm0.8\ )\ \%$		239
$\omega\gamma$	$(\ 2.62\pm0.13)\ \%$		159
ωe^+e^-	$(\ 2.0\ \pm0.4\ )\times10^{-4}$		159
$\gamma\gamma$	$(\ 2.22\pm0.08)\ \%$		479
$3\pi^0$	$(\ 2.54\pm0.18)\times10^{-3}$		430
$\mu^+\mu^-\gamma$	$(\ 1.09\pm0.27)\times10^{-4}$		467
$\pi^+\pi^-\mu^+\mu^-$	$< 2.9\ \times10^{-5}$	90%	401
$\pi^+\pi^-\pi^0$	$(\ 3.61\pm0.17)\times10^{-3}$		428
$(\pi^+\pi^-\pi^0)$ S-wave	$(\ 3.8\ \pm0.5\ )\times10^{-3}$		428
$\pi^\mp\rho^\pm$	$(\ 7.4\ \pm2.3\ )\times10^{-4}$		106
$\pi^0\rho^0$	$< 4\ \%$	90%	111
$2(\pi^+\pi^-)$	$(\ 8.6\ \pm0.9\ )\times10^{-5}$		372

$\pi^+\pi^-2\pi^0$			$(1.8\ \pm0.4\ )\times10^{-4}$		376
$2(\pi^+\pi^-)$ neutrals			<1 %	95%	–
$2(\pi^+\pi^-)\pi^0$			$<1.8\ \times10^{-3}$	90%	298
$2(\pi^+\pi^-)2\pi^0$			<1 %	95%	197
$3(\pi^+\pi^-)$			$<3.1\ \times10^{-5}$	90%	189
$K^\pm\pi^\mp$			$<4\ \times10^{-5}$	90%	334
$\pi^+\pi^-e^+e^-$			$(2.4\ ^{+1.3}_{-1.0})\times10^{-3}$		458
$\pi^+e^-\nu_e+$ c.c.			$<2.1\ \times10^{-4}$	90%	469
γe^+e^-			$(4.73\pm0.30)\times10^{-4}$		479
$\pi^0\gamma\gamma$			$(3.20\pm0.24)\times10^{-3}$		469
$\pi^0\gamma\gamma$(non resonant)			$(6.2\ \pm0.9\ )\times10^{-4}$		–
$4\pi^0$			$<3.2\ \times10^{-4}$	90%	380
e^+e^-			$<5.6\ \times10^{-9}$	90%	479
invisible			$<5\ \times10^{-4}$	90%	–

Charge conjugation (C), Parity (P),
Lepton family number (LF) violating modes

$\pi^+\pi^-$	P,CP		$<1.8\ \times10^{-5}$	90%	458
$\pi^0\pi^0$	P,CP		$<5\ \times10^{-4}$	90%	459
$\pi^0e^+e^-$	C	[f]	$<1.4\ \times10^{-3}$	90%	469
ηe^+e^-	C	[f]	$<2.4\ \times10^{-3}$	90%	322
3γ	C		$<1.1\ \times10^{-4}$	90%	479
$\mu^+\mu^-\pi^0$	C	[f]	$<6.0\ \times10^{-5}$	90%	445
$\mu^+\mu^-\eta$	C	[f]	$<1.5\ \times10^{-5}$	90%	273
$e\mu$	LF		$<4.7\ \times10^{-4}$	90%	473

$f_0(980)$ [j]

$I^G(J^{PC})=0^+(0^{++})$

Mass $m=990\pm20$ MeV
Full width $\Gamma=10$ to 100 MeV

f_0(980) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	dominant	476

See Particle Listings for 2 decay modes that have been seen / not seen.

$a_0(980)$ [j]

$I^G(J^{PC})=1^-(0^{++})$

Mass $m=980\pm20$ MeV
Full width $\Gamma=50$ to 100 MeV

a_0(980) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\eta\pi$	dominant	319

See Particle Listings for 2 decay modes that have been seen / not seen.

$\phi(1020)$

$I^G(J^{PC})=0^-(1^{--})$

Mass $m=1019.461\pm0.016$ MeV
Full width $\Gamma=4.249\pm0.013$ MeV (S = 1.1)

ϕ(1020) DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
K^+K^-	$(49.2\ \pm0.5\ )$ %	S=1.3	127
$K^0_LK^0_S$	$(34.0\ \pm0.4\ )$ %	S=1.3	110

$\rho\pi + \pi^+\pi^-\pi^0$		(15.24 ± 0.33) %	S=1.2	–
$\eta\gamma$		(1.303 ± 0.025) %	S=1.2	363
$\pi^0\gamma$		$(1.30 \pm 0.05) \times 10^{-3}$		501
$\ell^+\ell^-$		—		510
e^+e^-		$(2.973 \pm 0.034) \times 10^{-4}$	S=1.3	510
$\mu^+\mu^-$		$(2.86 \pm 0.19) \times 10^{-4}$		499
ηe^+e^-		$(1.08 \pm 0.04) \times 10^{-4}$		363
$\pi^+\pi^-$		$(7.3 \pm 1.3) \times 10^{-5}$		490
$\omega\pi^0$		$(4.7 \pm 0.5) \times 10^{-5}$		171
$\omega\gamma$		< 5 %	CL=84%	209
$\rho\gamma$		$< 1.2 \times 10^{-5}$	CL=90%	215
$\pi^+\pi^-\gamma$		$(4.1 \pm 1.3) \times 10^{-5}$		490
$f_0(980)\gamma$		$(3.22 \pm 0.19) \times 10^{-4}$	S=1.1	29
$\pi^0\pi^0\gamma$		$(1.12 \pm 0.06) \times 10^{-4}$		492
$\pi^+\pi^-\pi^+\pi^-$		$(3.9 {}^{+2.8}_{-2.2}) \times 10^{-6}$		410
$\pi^+\pi^+\pi^-\pi^-\pi^0$		$< 4.6 \times 10^{-6}$	CL=90%	342
$\pi^0 e^+e^-$		$(1.33 {}^{+0.07}_{-0.10}) \times 10^{-5}$		501
$\pi^0\eta\gamma$		$(7.27 \pm 0.30) \times 10^{-5}$	S=1.5	346
$a_0(980)\gamma$		$(7.6 \pm 0.6) \times 10^{-5}$		39
$K^0\overline{K}^0\gamma$		$< 1.9 \times 10^{-8}$	CL=90%	110
$\eta'(958)\gamma$		$(6.22 \pm 0.21) \times 10^{-5}$		60
$\eta\pi^0\pi^0\gamma$		$< 2 \times 10^{-5}$	CL=90%	293
$\mu^+\mu^-\gamma$		$(1.4 \pm 0.5) \times 10^{-5}$		499
$\rho\gamma\gamma$		$< 1.2 \times 10^{-4}$	CL=90%	215
$\eta\pi^+\pi^-$		$< 1.8 \times 10^{-5}$	CL=90%	288
$\eta\mu^+\mu^-$		$< 9.4 \times 10^{-6}$	CL=90%	321
$\eta U \to \eta e^+e^-$		$< 1 \times 10^{-6}$	CL=90%	–
Lepton Family number (LF) violating modes				
$e^\pm\mu^\mp$	*LF*	$< 2 \times 10^{-6}$	CL=90%	504

$h_1(1170)$

$I^G(J^{PC}) = 0^-(1^{+-})$

Mass $m = 1170 \pm 20$ MeV
Full width $\Gamma = 360 \pm 40$ MeV

$b_1(1235)$

$I^G(J^{PC}) = 1^+(1^{+-})$

Mass $m = 1229.5 \pm 3.2$ MeV (S = 1.6)
Full width $\Gamma = 142 \pm 9$ MeV (S = 1.2)

$b_1(1235)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\omega\pi$	dominant		348
[D/S amplitude ratio = 0.277 ± 0.027]			
$\pi^\pm\gamma$	$(1.6 \pm 0.4) \times 10^{-3}$		607
$\pi^+\pi^+\pi^-\pi^0$	< 50 %	84%	535
$(K\overline{K})^\pm\pi^0$	< 8 %	90%	248
$K^0_S K^0_L \pi^\pm$	< 6 %	90%	235
$K^0_S K^0_S \pi^\pm$	< 2 %	90%	235
$\phi\pi$	< 1.5 %	84%	147

See Particle Listings for 2 decay modes that have been seen / not seen.

$a_1(1260)$ [k]

$I^G(J^{PC}) = 1^-(1^{++})$

Mass $m = 1230 \pm 40$ MeV [l]
Full width $\Gamma = 250$ to 600 MeV

$f_2(1270)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 1275.5 \pm 0.8$ MeV
Full width $\Gamma = 186.7^{+2.2}_{-2.5}$ MeV (S = 1.4)

$f_2(1270)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\pi\pi$	$(84.2\ ^{+2.9}_{-0.9})$ %	S=1.1	623
$\pi^+\pi^-2\pi^0$	$(7.7\ ^{+1.1}_{-3.2})$ %	S=1.2	563
$K\overline{K}$	$(4.6\ ^{+0.5}_{-0.4})$ %	S=2.7	404
$2\pi^+2\pi^-$	(2.8 ± 0.4) %	S=1.2	560
$\eta\eta$	$(4.0 \pm 0.8) \times 10^{-3}$	S=2.1	326
$4\pi^0$	$(3.0 \pm 1.0) \times 10^{-3}$		565
$\gamma\gamma$	$(1.42 \pm 0.24) \times 10^{-5}$	S=1.4	638
$\eta\pi\pi$	$< 8 \times 10^{-3}$	CL=95%	478
$K^0K^-\pi^+ +$ c.c.	$< 3.4 \times 10^{-3}$	CL=95%	293
e^+e^-	$< 6 \times 10^{-10}$	CL=90%	638

$f_1(1285)$

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 1281.9 \pm 0.5$ MeV (S = 1.8)
Full width $\Gamma = 22.7 \pm 1.1$ MeV (S = 1.5)

$f_1(1285)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
4π	$(33.5\ ^{+\ 2.0}_{-\ 1.8})$ %	S=1.3	568
$\pi^0\pi^0\pi^+\pi^-$	$(22.3\ ^{+\ 1.3}_{-\ 1.2})$ %	S=1.3	566
$2\pi^+2\pi^-$	$(11.2\ ^{+\ 0.7}_{-\ 0.6})$ %	S=1.3	563
$\rho^0\pi^+\pi^-$	$(11.2\ ^{+\ 0.7}_{-\ 0.6})$ %	S=1.3	336
$4\pi^0$	$< 7 \times 10^{-4}$	CL=90%	568
$\eta\pi^+\pi^-$	(35 ± 15) %		479
$\eta\pi\pi$	$(52.0\ ^{+\ 1.8}_{-\ 2.1})$ %	S=1.2	482
$a_0(980)\pi$ [ignoring $a_0(980) \to K\overline{K}$]	(38 ± 4) %		238
$\eta\pi\pi$ [excluding $a_0(980)\pi$]	(14 ± 4) %		482
$K\overline{K}\pi$	(9.1 ± 0.4) %	S=1.1	308
$\pi^+\pi^-\pi^0$	$(3.0 \pm 0.9) \times 10^{-3}$		603
$\rho^{\pm}\pi^{\mp}$	$< 3.1 \times 10^{-3}$	CL=95%	390
$\gamma\rho^0$	(5.3 ± 1.2) %	S=2.9	406
$\phi\gamma$	$(7.5 \pm 2.7) \times 10^{-4}$		236

See Particle Listings for 2 decay modes that have been seen / not seen.

$\eta(1295)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 1294 \pm 4$ MeV (S = 1.6)
Full width $\Gamma = 55 \pm 5$ MeV

$\pi(1300)$

$I^G(J^{PC}) = 1^-(0^{-+})$

Mass $m = 1300 \pm 100$ MeV [l]
Full width $\Gamma = 200$ to 600 MeV

$a_2(1320)$

$I^G(J^{PC}) = 1^-(2^{++})$

Mass $m = 1318.3^{+0.5}_{-0.6}$ MeV (S = 1.2)
Full width $\Gamma = 107 \pm 5$ MeV [l]

$a_2(1320)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
3π	(70.1 ± 2.7) %	S=1.2	624
$\eta\pi$	(14.5 ± 1.2) %		535
$\omega\pi\pi$	(10.6 ± 3.2) %	S=1.3	366
$K\overline{K}$	(4.9 ± 0.8) %		437
$\eta'(958)\pi$	$(5.5 \pm 0.9) \times 10^{-3}$		288
$\pi^{\pm}\gamma$	$(2.91 \pm 0.27) \times 10^{-3}$		652
$\gamma\gamma$	$(9.4 \pm 0.7) \times 10^{-6}$		659
e^+e^-	$< 5 \times 10^{-9}$	CL=90%	659

$f_0(1370)$ [j]

$I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 1200$ to 1500 MeV
Full width $\Gamma = 200$ to 500 MeV

$f_0(1370)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\rho\rho$	dominant	†

See Particle Listings for 15 decay modes that have been seen / not seen.

$\pi_1(1400)$ [n]

$I^G(J^{PC}) = 1^-(1^{-+})$

Mass $m = 1354 \pm 25$ MeV (S = 1.8)
Full width $\Gamma = 330 \pm 35$ MeV

$\eta(1405)$ [o]

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 1408.8 \pm 1.8$ MeV [l] (S = 2.1)
Full width $\Gamma = 51.0 \pm 2.9$ MeV [l] (S = 1.8)

$\eta(1405)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\rho\rho$	<58 %	99.85%	†

See Particle Listings for 9 decay modes that have been seen / not seen.

$f_1(1420)$ [p]

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 1426.4 \pm 0.9$ MeV (S = 1.1)
Full width $\Gamma = 54.9 \pm 2.6$ MeV

$f_1(1420)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}\pi$	dominant	438
$K\overline{K}^*(892)+$ c.c.	dominant	163

See Particle Listings for 2 decay modes that have been seen / not seen.

$\omega(1420)$ [q]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass m (1400–1450) MeV
Full width Γ (180–250) MeV

$\omega(1420)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\rho\pi$	dominant	486

See Particle Listings for 3 decay modes that have been seen / not seen.

$a_0(1450)$ [j]

$I^G(J^{PC}) = 1^-(0^{++})$

Mass $m = 1474 \pm 19$ MeV
Full width $\Gamma = 265 \pm 13$ MeV

$a_0(1450)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\eta$	0.093 ± 0.020	627
$\pi\eta'(958)$	0.033 ± 0.017	410
$K\overline{K}$	0.082 ± 0.028	547
$\omega\pi\pi$	**DEFINED AS 1**	484

See Particle Listings for 2 decay modes that have been seen / not seen.

$\rho(1450)$ [r]

$I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 1465 \pm 25$ MeV [l]
Full width $\Gamma = 400 \pm 60$ MeV [l]

$\eta(1475)$ [o]

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 1476 \pm 4$ MeV (S = 1.3)
Full width $\Gamma = 85 \pm 9$ MeV (S = 1.5)

$\eta(1475)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}\pi$	dominant	477

See Particle Listings for 4 decay modes that have been seen / not seen.

$f_0(1500)$ [n]

$I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 1504 \pm 6$ MeV (S = 1.3)
Full width $\Gamma = 109 \pm 7$ MeV

$f_0(1500)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
$\pi\pi$	(34.9 ± 2.3) %	1.2	740
4π	(49.5 ± 3.3) %	1.2	691
$\eta\eta$	(5.1 ± 0.9) %	1.4	515
$\eta\eta'(958)$	(1.9 ± 0.8) %	1.7	†
$K\overline{K}$	(8.6 ± 1.0) %	1.1	568

See Particle Listings for 9 decay modes that have been seen / not seen.

$f_2'(1525)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 1525 \pm 5$ MeV [l]
Full width $\Gamma = 73^{+6}_{-5}$ MeV [l]

$f_2'(1525)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}$	(88.7 ± 2.2) %	581
$\eta\eta$	(10.4 ± 2.2) %	530
$\pi\pi$	$(8.2\pm1.5)\times10^{-3}$	750
$\gamma\gamma$	$(1.10\pm0.14)\times10^{-6}$	763

$\pi_1(1600)$ [n]

$I^G(J^{PC}) = 1^-(1^{-+})$

Mass $m = 1662^{+8}_{-9}$ MeV
Full width $\Gamma = 241 \pm 40$ MeV (S = 1.4)

$\eta_2(1645)$

$I^G(J^{PC}) = 0^+(2^{-+})$

Mass $m = 1617 \pm 5$ MeV
Full width $\Gamma = 181 \pm 11$ MeV

$\omega(1650)$ [s]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 1670 \pm 30$ MeV
Full width $\Gamma = 315 \pm 35$ MeV

$\omega_3(1670)$

$I^G(J^{PC}) = 0^-(3^{--})$

Mass $m = 1667 \pm 4$ MeV
Full width $\Gamma = 168 \pm 10$ MeV [l]

$\pi_2(1670)$

$I^G(J^{PC}) = 1^-(2^{-+})$

Mass $m = 1672.2 \pm 3.0$ MeV [l] (S = 1.4)
Full width $\Gamma = 260 \pm 9$ MeV [l] (S = 1.2)

$\pi_2(1670)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
3π	(95.8 ± 1.4) %		809
$f_2(1270)\pi$	(56.3 ± 3.2) %		328
$\rho\pi$	$(31\ \pm4\ )$ %		648
$\sigma\pi$	(10.9 ± 3.4) %		–
$\pi(\pi\pi)_{S\text{-wave}}$	$(\ 8.7\pm3.4)$ %		–
$K\overline{K}^*(892)+$ c.c.	$(\ 4.2\pm1.4)$ %		455
$\omega\rho$	$(\ 2.7\pm1.1)$ %		304
$\pi^\pm\gamma$	$(\ 7.0\pm1.1)\times10^{-4}$		830
$\gamma\gamma$	$<\ 2.8\ \times10^{-7}$	90%	836
$\rho(1450)\pi$	$<\ 3.6\ \times10^{-3}$	97.7%	147
$b_1(1235)\pi$	$<\ 1.9\ \times10^{-3}$	97.7%	365

See Particle Listings for 2 decay modes that have been seen / not seen.

$\phi(1680)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 1680 \pm 20$ MeV [l]
Full width $\Gamma = 150 \pm 50$ MeV [l]

$\phi(1680)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}^*(892)+$ c.c.	dominant	462

See Particle Listings for 7 decay modes that have been seen / not seen.

$\rho_3(1690)$

$I^G(J^{PC}) = 1^+(3^{--})$

Mass $m = 1688.8 \pm 2.1$ MeV [l]
Full width $\Gamma = 161 \pm 10$ MeV [l] (S = 1.5)

$\rho_3(1690)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
4π	$(71.1\ \pm\ 1.9\ )$ %		790
$\pi^\pm\pi^+\pi^-\pi^0$	$(67\ \pm22\ )$ %		787
$\omega\pi$	$(16\ \pm\ 6\ )$ %		655
$\pi\pi$	$(23.6\ \pm\ 1.3\ )$ %		834
$K\overline{K}\pi$	$(\ 3.8\ \pm\ 1.2\ )$ %		629
$K\overline{K}$	$(\ 1.58\pm\ 0.26)$ %	1.2	685

See Particle Listings for 5 decay modes that have been seen / not seen.

$\rho(1700)$ [r]

$I^G(J^{PC}) = 1^+(1^{--})$

Mass $m = 1720 \pm 20$ MeV [l] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)
Full width $\Gamma = 250 \pm 100$ MeV [l] ($\eta\rho^0$ and $\pi^+\pi^-$ modes)

$\rho(1700)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$2(\pi^+\pi^-)$	large	803
$\rho\pi\pi$	dominant	653
$\rho^0\pi^+\pi^-$	large	651
$\rho^\pm\pi^\mp\pi^0$	large	652

See Particle Listings for 12 decay modes that have been seen / not seen.

$f_0(1710)$ [t]

$I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 1723^{+6}_{-5}$ MeV (S = 1.6)
Full width $\Gamma = 139 \pm 8$ MeV (S = 1.1)

$\pi(1800)$

$I^G(J^{PC}) = 1^-(0^{-+})$

Mass $m = 1812 \pm 12$ MeV (S = 2.3)
Full width $\Gamma = 208 \pm 12$ MeV

$\phi_3(1850)$

$I^G(J^{PC}) = 0^-(3^{--})$

Mass $m = 1854 \pm 7$ MeV
Full width $\Gamma = 87^{+28}_{-23}$ MeV (S = 1.2)

$\pi_2(1880)$

$I^G(J^{PC}) = 1^-(2^{-+})$

Mass $m = 1895 \pm 16$ MeV
Full width $\Gamma = 235 \pm 34$ MeV

$f_2(1950)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 1944 \pm 12$ MeV (S = 1.5)
Full width $\Gamma = 472 \pm 18$ MeV

$f_2(2010)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 2011^{+60}_{-80}$ MeV
Full width $\Gamma = 202 \pm 60$ MeV

$a_4(2040)$

$I^G(J^{PC}) = 1^-(4^{++})$

Mass $m = 1995^{+10}_{-8}$ MeV (S = 1.1)
Full width $\Gamma = 257^{+25}_{-23}$ MeV (S = 1.3)

$f_4(2050)$

$I^G(J^{PC}) = 0^+(4^{++})$

Mass $m = 2018 \pm 11$ MeV (S = 2.1)
Full width $\Gamma = 237 \pm 18$ MeV (S = 1.9)

$f_4(2050)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	(17.0 ± 1.5) %	1000
$K\overline{K}$	$(6.8^{+3.4}_{-1.8}) \times 10^{-3}$	880
$\eta\eta$	$(2.1\pm0.8) \times 10^{-3}$	848
$4\pi^0$	$<$ 1.2 %	964

See Particle Listings for 2 decay modes that have been seen / not seen.

$\phi(2170)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 2188 \pm 10$ MeV (S = 1.8)
Full width $\Gamma = 83 \pm 12$ MeV

$f_2(2300)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 2297 \pm 28$ MeV
Full width $\Gamma = 149 \pm 40$ MeV

$f_2(2340)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 2345^{+50}_{-40}$ MeV
Full width $\Gamma = 322^{+70}_{-60}$ MeV

STRANGE MESONS
($S = \pm1$, $C = B = 0$)

$K^+ = u\overline{s}$, $K^0 = d\overline{s}$, $\overline{K}^0 = \overline{d}s$, $K^- = \overline{u}s$, similarly for K^*'s

$K^\pm$

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 493.677 \pm 0.016$ MeV [u] (S = 2.8)
Mean life $\tau = (1.2380 \pm 0.0020) \times 10^{-8}$ s (S = 1.8)
$c\tau = 3.711$ m

CPT violation parameters (Δ = rate difference/sum)

$\Delta(K^\pm \to \mu^\pm \nu_\mu) = (-0.27 \pm 0.21)\%$
$\Delta(K^\pm \to \pi^\pm \pi^0) = (0.4 \pm 0.6)\%$ [v]

CP violation parameters (Δ = rate difference/sum)

$\Delta(K^\pm \to \pi^\pm e^+ e^-) = (-2.2 \pm 1.6) \times 10^{-2}$
$\Delta(K^\pm \to \pi^\pm \mu^+ \mu^-) = 0.010 \pm 0.023$
$\Delta(K^\pm \to \pi^\pm \pi^0 \gamma) = (0.0 \pm 1.2) \times 10^{-3}$
$\Delta(K^\pm \to \pi^\pm \pi^+ \pi^-) = (0.04 \pm 0.06)\%$
$\Delta(K^\pm \to \pi^\pm \pi^0 \pi^0) = (-0.02 \pm 0.28)\%$

T violation parameters

$K^+ \to \pi^0 \mu^+ \nu_\mu$ $P_T = (-1.7 \pm 2.5) \times 10^{-3}$
$K^+ \to \mu^+ \nu_\mu \gamma$ $P_T = (-0.6 \pm 1.9) \times 10^{-2}$
$K^+ \to \pi^0 \mu^+ \nu_\mu$ $\text{Im}(\xi) = -0.006 \pm 0.008$

Slope parameter g [x]

(See Particle Listings for quadratic coefficients and alternative parametrization related to $\pi\pi$ scattering)

$K^\pm \to \pi^\pm \pi^+ \pi^-$ $g = -0.21134 \pm 0.00017$
$(g_+ - g_-) / (g_+ + g_-) = (-1.5 \pm 2.2) \times 10^{-4}$
$K^\pm \to \pi^\pm \pi^0 \pi^0$ $g = 0.626 \pm 0.007$
$(g_+ - g_-) / (g_+ + g_-) = (1.8 \pm 1.8) \times 10^{-4}$

$K^{\pm}$ decay form factors [a,y]

Assuming μ-e universality

$\lambda_+(K^+_{\mu 3}) = \lambda_+(K^+_{e3}) = (2.97 \pm 0.05) \times 10^{-2}$

$\lambda_0(K^+_{\mu 3}) = (1.95 \pm 0.12) \times 10^{-2}$

Not assuming μ-e universality

$\lambda_+(K^+_{e3}) = (2.98 \pm 0.05) \times 10^{-2}$

$\lambda_+(K^+_{\mu 3}) = (2.96 \pm 0.17) \times 10^{-2}$

$\lambda_0(K^+_{\mu 3}) = (1.96 \pm 0.13) \times 10^{-2}$

K_{e3} form factor quadratic fit

$\lambda'_+ \ (K^{\pm}_{e3})$ linear coeff. $= (2.49 \pm 0.17) \times 10^{-2}$

$\lambda''_+(K^{\pm}_{e3})$ quadratic coeff. $= (0.19 \pm 0.09) \times 10^{-2}$

K^+_{e3} $\left|f_S/f_+\right| = (-0.3^{+0.8}_{-0.7}) \times 10^{-2}$

K^+_{e3} $\left|f_T/f_+\right| = (-1.2 \pm 2.3) \times 10^{-2}$

$K^+_{\mu 3}$ $\left|f_S/f_+\right| = (0.2 \pm 0.6) \times 10^{-2}$

$K^+_{\mu 3}$ $\left|f_T/f_+\right| = (-0.1 \pm 0.7) \times 10^{-2}$

$K^+ \rightarrow e^+ \nu_e \gamma$ $\left|F_A + F_V\right| = 0.133 \pm 0.008$ (S = 1.3)

$K^+ \rightarrow \mu^+ \nu_\mu \gamma$ $\left|F_A + F_V\right| = 0.165 \pm 0.013$

$K^+ \rightarrow e^+ \nu_e \gamma$ $\left|F_A - F_V\right| < 0.49$, CL = 90%

$K^+ \rightarrow \mu^+ \nu_\mu \gamma$ $\left|F_A - F_V\right| = -0.21 \pm 0.06$

Charge radius

$\langle r \rangle = 0.560 \pm 0.031$ fm

Forward-backward asymmetry

$A_{FB}(K^{\pm}_{\pi\mu\mu}) = \frac{\Gamma(cos(\theta_{K\mu})>0)-\Gamma(cos(\theta_{K\mu})<0)}{\Gamma(cos(\theta_{K\mu})>0)+\Gamma(cos(\theta_{K\mu})<0)} < 2.3 \times 10^{-2}$, CL = 90%

K^- modes are charge conjugates of the modes below.

K^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Leptonic and semileptonic modes			
$e^+ \nu_e$	$(1.582 \pm 0.007) \times 10^{-5}$		247
$\mu^+ \nu_\mu$	(63.56 ± 0.11) %	S=1.2	236
$\pi^0 e^+ \nu_e$	(5.07 ± 0.04) %	S=2.1	228
Called K^+_{e3}.			
$\pi^0 \mu^+ \nu_\mu$	(3.352 ± 0.033) %	S=1.9	215
Called $K^+_{\mu 3}$.			
$\pi^0 \pi^0 e^+ \nu_e$	$(2.55 \pm 0.04) \times 10^{-5}$	S=1.1	206
$\pi^+ \pi^- e^+ \nu_e$	$(4.247 \pm 0.024) \times 10^{-5}$		203
$\pi^+ \pi^- \mu^+ \nu_\mu$	$(1.4 \pm 0.9) \times 10^{-5}$		151
$\pi^0 \pi^0 \pi^0 e^+ \nu_e$	$< 3.5 \times 10^{-6}$	CL=90%	135
Hadronic modes			
$\pi^+ \pi^0$	(20.67 ± 0.08) %	S=1.2	205
$\pi^+ \pi^0 \pi^0$	(1.760 ± 0.023) %	S=1.1	133
$\pi^+ \pi^+ \pi^-$	(5.583 ± 0.024) %		125

Leptonic and semileptonic modes with photons						
$\mu^+ \nu_\mu \gamma$	[z,aa]	(	6.2 ± 0.8	$) \times 10^{-3}$		236
$\mu^+ \nu_\mu \gamma(\mathrm{SD}^+)$	[a,bb]	(	1.33 ± 0.22	$) \times 10^{-5}$		–
$\mu^+ \nu_\mu \gamma(\mathrm{SD}^+\mathrm{INT})$	[a,bb]	$<$	2.7	$\times 10^{-5}$	CL=90%	–
$\mu^+ \nu_\mu \gamma(\mathrm{SD}^- + \mathrm{SD}^-\mathrm{INT})$	[a,bb]	$<$	2.6	$\times 10^{-4}$	CL=90%	–
$e^+ \nu_e \gamma$		(	9.4 ± 0.4	$) \times 10^{-6}$		247
$\pi^0 e^+ \nu_e \gamma$	[z,aa]	(	2.56 ± 0.16	$) \times 10^{-4}$		228
$\pi^0 e^+ \nu_e \gamma(\mathrm{SD})$	[a,bb]	$<$	5.3	$\times 10^{-5}$	CL=90%	228
$\pi^0 \mu^+ \nu_\mu \gamma$	[z,aa]	(	1.25 ± 0.25	$) \times 10^{-5}$		215
$\pi^0 \pi^0 e^+ \nu_e \gamma$		$<$	5	$\times 10^{-6}$	CL=90%	206
Hadronic modes with photons or $\ell\overline{\ell}$ pairs						
$\pi^+ \pi^0 \gamma(\mathrm{INT})$		(–	4.2 ± 0.9	$) \times 10^{-6}$		–
$\pi^+ \pi^0 \gamma(\mathrm{DE})$	[z,cc]	(	6.0 ± 0.4	$) \times 10^{-6}$		205
$\pi^+ \pi^0 \pi^0 \gamma$	[z,aa]	(	$7.6 \begin{smallmatrix}+6.0\\-3.0\end{smallmatrix}$	$) \times 10^{-6}$		133
$\pi^+ \pi^+ \pi^- \gamma$	[z,aa]	(	1.04 ± 0.31	$) \times 10^{-4}$		125
$\pi^+ \gamma \gamma$	[z]	(	1.01 ± 0.06	$) \times 10^{-6}$		227
$\pi^+ 3\gamma$	[z]	$<$	1.0	$\times 10^{-4}$	CL=90%	227
$\pi^+ e^+ e^- \gamma$		(	1.19 ± 0.13	$) \times 10^{-8}$		227
Leptonic modes with $\ell\overline{\ell}$ pairs						
$e^+ \nu_e \nu \overline{\nu}$		$<$	6	$\times 10^{-5}$	CL=90%	247
$\mu^+ \nu_\mu \nu \overline{\nu}$		$<$	2.4	$\times 10^{-6}$	CL=90%	236
$e^+ \nu_e e^+ e^-$		(	2.48 ± 0.20	$) \times 10^{-8}$		247
$\mu^+ \nu_\mu e^+ e^-$		(	7.06 ± 0.31	$) \times 10^{-8}$		236
$e^+ \nu_e \mu^+ \mu^-$		(	1.7 ± 0.5	$) \times 10^{-8}$		223
$\mu^+ \nu_\mu \mu^+ \mu^-$		$<$	4.1	$\times 10^{-7}$	CL=90%	185
Lepton family number (*LF*), Lepton number (*L*), $\Delta S = \Delta Q$ (*SQ*) violating modes, or $\Delta S = 1$ weak neutral current (*S1*) modes						
$\pi^+ \pi^+ e^- \overline{\nu}_e$	*SQ*	$<$	1.3	$\times 10^{-8}$	CL=90%	203
$\pi^+ \pi^+ \mu^- \overline{\nu}_\mu$	*SQ*	$<$	3.0	$\times 10^{-6}$	CL=95%	151
$\pi^+ e^+ e^-$	*S1*	(	3.00 ± 0.09	$) \times 10^{-7}$		227
$\pi^+ \mu^+ \mu^-$	*S1*	(	9.4 ± 0.6	$) \times 10^{-8}$	S=2.6	172
$\pi^+ \nu \overline{\nu}$	*S1*	(	1.7 ± 1.1	$) \times 10^{-10}$		227
$\pi^+ \pi^0 \nu \overline{\nu}$	*S1*	$<$	4.3	$\times 10^{-5}$	CL=90%	205
$\mu^- \nu e^+ e^+$	*LF*	$<$	2.1	$\times 10^{-8}$	CL=90%	236
$\mu^+ \nu_e$	*LF* [d]	$<$	4	$\times 10^{-3}$	CL=90%	236
$\pi^+ \mu^+ e^-$	*LF*	$<$	1.3	$\times 10^{-11}$	CL=90%	214
$\pi^+ \mu^- e^+$	*LF*	$<$	5.2	$\times 10^{-10}$	CL=90%	214
$\pi^- \mu^+ e^+$	*L*	$<$	5.0	$\times 10^{-10}$	CL=90%	214
$\pi^- e^+ e^+$	*L*	$<$	6.4	$\times 10^{-10}$	CL=90%	227
$\pi^- \mu^+ \mu^+$	*L* [d]	$<$	8.6	$\times 10^{-11}$	CL=90%	172
$\mu^+ \overline{\nu}_e$	*L* [d]	$<$	3.3	$\times 10^{-3}$	CL=90%	236
$\pi^0 e^+ \overline{\nu}_e$	*L*	$<$	3	$\times 10^{-3}$	CL=90%	228
$\pi^+ \gamma$	[dd]	$<$	2.3	$\times 10^{-9}$	CL=90%	227

K^0

$I(J^P) = \frac{1}{2}(0^-)$

50% K_S, 50% K_L

Mass $m = 497.611 \pm 0.013$ MeV (S = 1.2)

$m_{K^0} - m_{K^\pm} = 3.934 \pm 0.020$ MeV (S = 1.6)

Mean square charge radius

$\langle r^2 \rangle = -0.077 \pm 0.010$ fm^2

***T*-violation parameters in K^0-$\overline{K}^0$ mixing** [y]

Asymmetry A_T in K^0-$\overline{K}^0$ mixing $= (6.6 \pm 1.6) \times 10^{-3}$

***CP*-violation parameters**

Re(ϵ) $= (1.596 \pm 0.013) \times 10^{-3}$

***CPT*-violation parameters** [y]

Re $\delta = (2.5 \pm 2.3) \times 10^{-4}$
Im $\delta = (-1.5 \pm 1.6) \times 10^{-5}$
Re(y), K_{e3} parameter $= (0.4 \pm 2.5) \times 10^{-3}$
Re(x$_-$), K_{e3} parameter $= (-2.9 \pm 2.0) \times 10^{-3}$
$|m_{K^0} - m_{\overline{K}^0}| \,/\, m_{\text{average}} < 6 \times 10^{-19}$, CL = 90% [ee]
$(\Gamma_{K^0} - \Gamma_{\overline{K}^0})/m_{\text{average}} = (8 \pm 8) \times 10^{-18}$

Tests of $\Delta S = \Delta Q$

Re(x$_+$), K_{e3} parameter $= (-0.9 \pm 3.0) \times 10^{-3}$

K^0_S

$I(J^P) = \frac{1}{2}(0^-)$

Mean life $\tau = (0.8954 \pm 0.0004) \times 10^{-10}$ s (S = 1.1) Assuming *CPT*
Mean life $\tau = (0.89564 \pm 0.00033) \times 10^{-10}$ s Not assuming *CPT*
$c\tau = 2.6844$ cm Assuming *CPT*

***CP*-violation parameters** [ff]

Im(η_{+-0}) $= -0.002 \pm 0.009$
Im(η_{000}) $= -0.001 \pm 0.016$
$|\eta_{000}| = |A(K^0_S \to 3\pi^0)/A(K^0_L \to 3\pi^0)| < 0.0088$, CL = 90%
CP asymmetry *A* in $\pi^+\pi^- e^+ e^-$ $= (-0.4 \pm 0.8)\%$

K^0_S DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes				
$\pi^0\pi^0$		(30.69±0.05) %		209
$\pi^+\pi^-$		(69.20±0.05) %		206
$\pi^+\pi^-\pi^0$		$(3.5\ ^{+1.1}_{-0.9}) \times 10^{-7}$		133
Modes with photons or $\ell\overline{\ell}$ pairs				
$\pi^+\pi^-\gamma$	[aa,gg]	$(1.79\pm0.05) \times 10^{-3}$		206
$\pi^+\pi^- e^+ e^-$		$(4.79\pm0.15) \times 10^{-5}$		206
$\pi^0\gamma\gamma$	[gg]	$(4.9\ \pm1.8) \times 10^{-8}$		230
$\gamma\gamma$		$(2.63\pm0.17) \times 10^{-6}$	S=3.0	249
Semileptonic modes				
$\pi^\pm e^\mp \nu_e$	[hh]	$(7.04\pm0.08) \times 10^{-4}$		229
***CP* violating (*CP*) and $\Delta S = 1$ weak neutral current (*S1*) modes**				
$3\pi^0$	*CP*	$< 2.6 \times 10^{-8}$	CL=90%	139
$\mu^+\mu^-$	*S1*	$< 8 \times 10^{-10}$	CL=90%	225
e^+e^-	*S1*	$< 9 \times 10^{-9}$	CL=90%	249

$\pi^0 e^+ e^-$	S1	[gg]	$(3.0\ {}^{+1.5}_{-1.2}) \times 10^{-9}$	230
$\pi^0 \mu^+ \mu^-$	S1		$(2.9\ {}^{+1.5}_{-1.2}) \times 10^{-9}$	177

K^0_L

$I(J^P) = \frac{1}{2}(0^-)$

$m_{K_L} - m_{K_S}$
$= (0.5293 \pm 0.0009) \times 10^{10}\ \hbar\ s^{-1}$ (S = 1.3) Assuming *CPT*
$= (3.484 \pm 0.006) \times 10^{-12}$ MeV Assuming *CPT*
$= (0.5289 \pm 0.0010) \times 10^{10}\ \hbar\ s^{-1}$ Not assuming *CPT*
Mean life $\tau = (5.116 \pm 0.021) \times 10^{-8}$ s (S = 1.1)
$c\tau = 15.34$ m

Slope parameters [x]

(See Particle Listings for other linear and quadratic coefficients)

$K^0_L \to \pi^+\pi^-\pi^0$: $g = 0.678 \pm 0.008$ (S = 1.5)
$K^0_L \to \pi^+\pi^-\pi^0$: $h = 0.076 \pm 0.006$
$K^0_L \to \pi^+\pi^-\pi^0$: $k = 0.0099 \pm 0.0015$
$K^0_L \to \pi^0\pi^0\pi^0$: $h = (0.6 \pm 1.2) \times 10^{-3}$

K_L decay form factors [y]

Linear parametrization assuming μ-e universality
$\lambda_+(K^0_{\mu 3}) = \lambda_+(K^0_{e3}) = (2.82 \pm 0.04) \times 10^{-2}$ (S = 1.1)
$\lambda_0(K^0_{\mu 3}) = (1.38 \pm 0.18) \times 10^{-2}$ (S = 2.2)

Quadratic parametrization assuming μ-e universality
$\lambda'_+(K^0_{\mu 3}) = \lambda'_+(K^0_{e3}) = (2.40 \pm 0.12) \times 10^{-2}$ (S = 1.2)
$\lambda''_+(K^0_{\mu 3}) = \lambda''_+(K^0_{e3}) = (0.20 \pm 0.05) \times 10^{-2}$ (S = 1.2)
$\lambda_0(K^0_{\mu 3}) = (1.16 \pm 0.09) \times 10^{-2}$ (S = 1.2)

Pole parametrization assuming μ-e universality
$M^{\mu}_V\ (K^0_{\mu 3}) = M^{e}_V\ (K^0_{e3}) = 878 \pm 6$ MeV (S = 1.1)
$M^{\mu}_S\ (K^0_{\mu 3}) = 1252 \pm 90$ MeV (S = 2.6)

Dispersive parametrization assuming μ-e universality
$\Lambda_+ = (0.251 \pm 0.006) \times 10^{-1}$ (S = 1.5)
$\ln(C) = (1.75 \pm 0.18) \times 10^{-1}$ (S = 2.0)

K^0_{e3} $|f_S/f_+| = (1.5^{+1.4}_{-1.6}) \times 10^{-2}$
K^0_{e3} $|f_T/f_+| = (5^{+4}_{-5}) \times 10^{-2}$
$K^0_{\mu 3}$ $|f_T/f_+| = (12 \pm 12) \times 10^{-2}$
$K_L \to \ell^+\ell^-\gamma$, $K_L \to \ell^+\ell^-\ell'^+\ell'^-$: $\alpha_{K^*} = -0.205 \pm 0.022$ (S = 1.8)
$K^0_L \to \ell^+\ell^-\gamma$, $K^0_L \to \ell^+\ell^-\ell'^+\ell'^-$: $\alpha_{DIP} = -1.69 \pm 0.08$ (S = 1.7)
$K_L \to \pi^+\pi^- e^+ e^-$: $a_1/a_2 = -0.737 \pm 0.014\ \text{GeV}^2$
$K_L \to \pi^0 2\gamma$: $a_V = -0.43 \pm 0.06$ (S = 1.5)

CP-violation parameters [ff]

$A_L = (0.332 \pm 0.006)\%$
$|\eta_{00}| = (2.220 \pm 0.011) \times 10^{-3}$ (S = 1.8)
$|\eta_{+-}| = (2.232 \pm 0.011) \times 10^{-3}$ (S = 1.8)
$|\epsilon| = (2.228 \pm 0.011) \times 10^{-3}$ (S = 1.8)
$|\eta_{00}/\eta_{+-}| = 0.9950 \pm 0.0007$ [ii] (S = 1.6)
$\mathrm{Re}(\epsilon'/\epsilon) = (1.66 \pm 0.23) \times 10^{-3}$ [ii] (S = 1.6)

Assuming *CPT*

$\phi_{+-} = (43.51 \pm 0.05)^\circ$ (S = 1.2)
$\phi_{00} = (43.52 \pm 0.05)^\circ$ (S = 1.3)
$\phi_\epsilon = \phi_{SW} = (43.52 \pm 0.05)^\circ$ (S = 1.2)

$\mathrm{Im}(\epsilon'/\epsilon) = -(\phi_{00} - \phi_{+-})/3 = (-0.002 \pm 0.005)^\circ$ (S = 1.7)

Not assuming *CPT*

$\phi_{+-} = (43.4 \pm 0.5)^\circ$ (S = 1.2)
$\phi_{00} = (43.7 \pm 0.6)^\circ$ (S = 1.2)
$\phi_\epsilon = (43.5 \pm 0.5)^\circ$ (S = 1.3)

CP asymmetry A in $K^0_L \to \pi^+\pi^- e^+ e^- = (13.7 \pm 1.5)\%$
β_{CP} from $K^0_L \to e^+ e^- e^+ e^- = -0.19 \pm 0.07$
γ_{CP} from $K^0_L \to e^+ e^- e^+ e^- = 0.01 \pm 0.11$ (S = 1.6)
j for $K^0_L \to \pi^+\pi^-\pi^0 = 0.0012 \pm 0.0008$
f for $K^0_L \to \pi^+\pi^-\pi^0 = 0.004 \pm 0.006$
$|\eta_{+-\gamma}| = (2.35 \pm 0.07) \times 10^{-3}$
$\phi_{+-\gamma} = (44 \pm 4)^\circ$
$|\epsilon'_{+-\gamma}|/\epsilon < 0.3$, CL = 90%
$|g_{E1}|$ for $K^0_L \to \pi^+\pi^-\gamma < 0.21$, CL = 90%

T-violation parameters

$\mathrm{Im}(\xi)$ in $K^0_{\mu 3} = -0.007 \pm 0.026$

CPT invariance tests

$\phi_{00} - \phi_{+-} = (0.34 \pm 0.32)^\circ$
$\mathrm{Re}(\frac{2}{3}\eta_{+-} + \frac{1}{3}\eta_{00}) - \frac{A_L}{2} = (-3 \pm 35) \times 10^{-6}$

$\Delta S = -\Delta Q$ in $K^0_{\ell 3}$ decay

$\mathrm{Re}\ x = -0.002 \pm 0.006$
$\mathrm{Im}\ x = 0.0012 \pm 0.0021$

K^0_L DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Semileptonic modes				
$\pi^\pm e^\mp \nu_e$	[hh]	(40.55 ± 0.11) %	S=1.7	229
Called K^0_{e3}.				
$\pi^\pm \mu^\mp \nu_\mu$	[hh]	(27.04 ± 0.07) %	S=1.1	216
Called $K^0_{\mu 3}$.				
$(\pi\mu\mathrm{atom})\nu$		$(1.05 \pm 0.11) \times 10^{-7}$		188
$\pi^0\pi^\pm e^\mp \nu$	[hh]	$(5.20 \pm 0.11) \times 10^{-5}$		207
$\pi^\pm e^\mp \nu e^+ e^-$	[hh]	$(1.26 \pm 0.04) \times 10^{-5}$		229

Hadronic modes, including Charge conjugation×Parity Violating (*CPV*) modes

$3\pi^0$			(19.52 ± 0.12) %	S=1.6	139
$\pi^+\pi^-\pi^0$			(12.54 ± 0.05) %		133
$\pi^+\pi^-$	*CPV*	[*jj*]	$(1.967 \pm 0.010) \times 10^{-3}$	S=1.5	206
$\pi^0\pi^0$	*CPV*		$(8.64 \pm 0.06) \times 10^{-4}$	S=1.8	209

Semileptonic modes with photons

$\pi^\pm e^\mp \nu_e \gamma$		[*aa,hh,kk*]	$(3.79 \pm 0.06) \times 10^{-3}$		229
$\pi^\pm \mu^\mp \nu_\mu \gamma$			$(5.65 \pm 0.23) \times 10^{-4}$		216

Hadronic modes with photons or $\ell\overline{\ell}$ pairs

$\pi^0\pi^0\gamma$			$< 2.43 \times 10^{-7}$	CL=90%	209
$\pi^+\pi^-\gamma$		[*aa,kk*]	$(4.15 \pm 0.15) \times 10^{-5}$	S=2.8	206
$\pi^+\pi^-\gamma$(DE)			$(2.84 \pm 0.11) \times 10^{-5}$	S=2.0	206
$\pi^0 2\gamma$		[*kk*]	$(1.273 \pm 0.033) \times 10^{-6}$		230
$\pi^0 \gamma e^+ e^-$			$(1.62 \pm 0.17) \times 10^{-8}$		230

Other modes with photons or $\ell\overline{\ell}$ pairs

2γ			$(5.47 \pm 0.04) \times 10^{-4}$	S=1.1	249
3γ			$< 7.4 \times 10^{-8}$	CL=90%	249
$e^+e^-\gamma$			$(9.4 \pm 0.4) \times 10^{-6}$	S=2.0	249
$\mu^+\mu^-\gamma$			$(3.59 \pm 0.11) \times 10^{-7}$	S=1.3	225
$e^+e^-\gamma\gamma$		[*kk*]	$(5.95 \pm 0.33) \times 10^{-7}$		249
$\mu^+\mu^-\gamma\gamma$		[*kk*]	$(1.0\ ^{+0.8}_{-0.6}) \times 10^{-8}$		225

Charge conjugation × Parity (*CP*) or Lepton Family number (*LF*) violating modes, or $\Delta S = 1$ weak neutral current (*S1*) modes

$\mu^+\mu^-$	*S1*		$(6.84 \pm 0.11) \times 10^{-9}$		225
e^+e^-	*S1*		$(9\ ^{+6}_{-4}) \times 10^{-12}$		249
$\pi^+\pi^-e^+e^-$	*S1*	[*kk*]	$(3.11 \pm 0.19) \times 10^{-7}$		206
$\pi^0\pi^0e^+e^-$	*S1*		$< 6.6 \times 10^{-9}$	CL=90%	209
$\pi^0\pi^0\mu^+\mu^-$	*S1*		$< 9.2 \times 10^{-11}$	CL=90%	57
$\mu^+\mu^-e^+e^-$	*S1*		$(2.69 \pm 0.27) \times 10^{-9}$		225
$e^+e^-e^+e^-$	*S1*		$(3.56 \pm 0.21) \times 10^{-8}$		249
$\pi^0\mu^+\mu^-$	*CP,S1*	[*ll*]	$< 3.8 \times 10^{-10}$	CL=90%	177
$\pi^0e^+e^-$	*CP,S1*	[*ll*]	$< 2.8 \times 10^{-10}$	CL=90%	230
$\pi^0\nu\overline{\nu}$	*CP,S1*	[*nn*]	$< 2.6 \times 10^{-8}$	CL=90%	230
$\pi^0\pi^0\nu\overline{\nu}$	*S1*		$< 8.1 \times 10^{-7}$	CL=90%	209
$e^\pm\mu^\mp$	*LF*	[*hh*]	$< 4.7 \times 10^{-12}$	CL=90%	238
$e^\pm e^\pm \mu^\mp \mu^\mp$	*LF*	[*hh*]	$< 4.12 \times 10^{-11}$	CL=90%	225
$\pi^0\mu^\pm e^\mp$	*LF*	[*hh*]	$< 7.6 \times 10^{-11}$	CL=90%	217
$\pi^0\pi^0\mu^\pm e^\mp$	*LF*		$< 1.7 \times 10^{-10}$	CL=90%	159

$K_0^*(700)$

$I(J^P) = \frac{1}{2}(0^+)$

Mass (T-Matrix Pole $\sqrt{s}$) = (630–730) − i (260–340) MeV
Mass (Breit-Wigner) = 824 ± 30 MeV
Full width (Breit-Wigner) = 478 ± 50 MeV

$K^*(892)$

$I(J^P) = \frac{1}{2}(1^-)$

$K^*(892)^{\pm}$ hadroproduced mass $m = 891.76 \pm 0.25$ MeV
$K^*(892)^{\pm}$ in τ decays mass $m = 895.5 \pm 0.8$ MeV
$K^*(892)^0$ mass $m = 895.55 \pm 0.20$ MeV (S = 1.7)
$K^*(892)^{\pm}$ hadroproduced full width $\Gamma = 50.3 \pm 0.8$ MeV
$K^*(892)^{\pm}$ in τ decays full width $\Gamma = 46.2 \pm 1.3$ MeV
$K^*(892)^0$ full width $\Gamma = 47.3 \pm 0.5$ MeV (S = 1.9)

$K^*(892)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\pi$	$\sim$ 100 %		290
$K^0\gamma$	$(2.46\pm0.21)\times10^{-3}$		307
$K^{\pm}\gamma$	$(1.00\pm0.09)\times10^{-3}$		309
$K\pi\pi$	$< 7 \times10^{-4}$	95%	223

$K_1(1270)$

$I(J^P) = \frac{1}{2}(1^+)$

Mass $m = 1272 \pm 7$ MeV [l]
Full width $\Gamma = 90 \pm 20$ MeV [l]

$K_1(1270)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\rho$	(42 ± 6) %	46
$K_0^*(1430)\pi$	(28 ± 4) %	†
$K^*(892)\pi$	(16 ± 5) %	302
$K\omega$	(11.0 ± 2.0) %	†
$Kf_0(1370)$	(3.0 ± 2.0) %	†

See Particle Listings for 1 decay modes that have been seen / not seen.

$K_1(1400)$

$I(J^P) = \frac{1}{2}(1^+)$

Mass $m = 1403 \pm 7$ MeV
Full width $\Gamma = 174 \pm 13$ MeV (S = 1.6)

$K_1(1400)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K^*(892)\pi$	(94 ± 6) %	402
$K\rho$	(3.0 ± 3.0) %	293
$Kf_0(1370)$	(2.0 ± 2.0) %	†
$K\omega$	(1.0 ± 1.0) %	284

See Particle Listings for 2 decay modes that have been seen / not seen.

$K^*(1410)$

$I(J^P) = \frac{1}{2}(1^-)$

Mass $m = 1421 \pm 9$ MeV
Full width $\Gamma = 236 \pm 18$ MeV

$K^*(1410)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K^*(892)\pi$	> 40 %	95%	416
$K\pi$	(6.6 ± 1.3) %		617
$K\rho$	< 7 %	95%	313
γK^0	$< 2.2 \times10^{-4}$	90%	623

$K_0^*(1430)$ [oo]

$I(J^P) = \frac{1}{2}(0^+)$

Mass $m = 1425 \pm 50$ MeV
Full width $\Gamma = 270 \pm 80$ MeV

$K_0^*(1430)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(93 ± 10) %	619
$K\eta$	$(8.6^{+2.7}_{-3.4})$ %	486

See Particle Listings for 1 decay modes that have been seen / not seen.

$K_2^*(1430)$

$I(J^P) = \frac{1}{2}(2^+)$

$K_2^*(1430)^\pm$ mass $m = 1425.6 \pm 1.5$ MeV (S = 1.1)
$K_2^*(1430)^0$ mass $m = 1432.4 \pm 1.3$ MeV
$K_2^*(1430)^\pm$ full width $\Gamma = 98.5 \pm 2.7$ MeV (S = 1.1)
$K_2^*(1430)^0$ full width $\Gamma = 109 \pm 5$ MeV (S = 1.9)

$K_2^*(1430)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$K\pi$	(49.9 ± 1.2) %		619
$K^*(892)\pi$	(24.7 ± 1.5) %		419
$K^*(892)\pi\pi$	(13.4 ± 2.2) %		372
$K\rho$	(8.7 ± 0.8) %	S=1.2	318
$K\omega$	(2.9 ± 0.8) %		311
$K^+\gamma$	$(2.4 \pm 0.5) \times 10^{-3}$	S=1.1	627
$K\eta$	$(1.5^{+3.4}_{-1.0}) \times 10^{-3}$	S=1.3	486
$K\omega\pi$	$< 7.2 \times 10^{-4}$	CL=95%	100
$K^0\gamma$	$< 9 \times 10^{-4}$	CL=90%	626

$K^*(1680)$

$I(J^P) = \frac{1}{2}(1^-)$

Mass $m = 1718 \pm 18$ MeV
Full width $\Gamma = 322 \pm 110$ MeV (S = 4.2)

$K^*(1680)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(38.7 ± 2.5) %	782
$K\rho$	$(31.4^{+5.0}_{-2.1})$ %	571
$K^*(892)\pi$	$(29.9^{+2.2}_{-5.0})$ %	618

See Particle Listings for 1 decay modes that have been seen / not seen.

$K_2(1770)$ [pp]

$I(J^P) = \frac{1}{2}(2^-)$

Mass $m = 1773 \pm 8$ MeV
Full width $\Gamma = 186 \pm 14$ MeV

$K_2(1770)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi\pi$		794
$K_2^*(1430)\pi$	dominant	288

See Particle Listings for 4 decay modes that have been seen / not seen.

$K_3^*(1780)$

$I(J^P) = \frac{1}{2}(3^-)$

Mass $m = 1776 \pm 7$ MeV (S = 1.1)
Full width $\Gamma = 159 \pm 21$ MeV (S = 1.3)

$K_3^*(1780)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\rho$	(31 ± 9) %		613
$K^*(892)\pi$	(20 ± 5) %		656
$K\pi$	(18.8 ± 1.0) %		813
$K\eta$	(30 ± 13) %		719
$K_2^*(1430)\pi$	< 16 %	95%	291

$K_2(1820)$ [qq]

$I(J^P) = \frac{1}{2}(2^-)$

Mass $m = 1819 \pm 12$ MeV
Full width $\Gamma = 264 \pm 34$ MeV

$K_4^*(2045)$

$I(J^P) = \frac{1}{2}(4^+)$

Mass $m = 2045 \pm 9$ MeV (S = 1.1)
Full width $\Gamma = 198 \pm 30$ MeV

$K_4^*(2045)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(9.9 ± 1.2) %	958
$K^*(892)\pi\pi$	(9 ± 5) %	802
$K^*(892)\pi\pi\pi$	(7 ± 5) %	768
$\rho K\pi$	(5.7 ± 3.2) %	741
$\omega K\pi$	(5.0 ± 3.0) %	738
$\phi K\pi$	(2.8 ± 1.4) %	594
$\phi K^*(892)$	(1.4 ± 0.7) %	363

CHARMED MESONS
$(C = \pm 1)$

$D^+ = c\overline{d}$, $D^0 = c\overline{u}$, $\overline{D}^0 = \overline{c}\,u$, $D^- = \overline{c}\,d$, similarly for D^*'s

$D^\pm$

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 1869.65 \pm 0.05$ MeV
Mean life $\tau = (1040 \pm 7) \times 10^{-15}$ s
$c\tau = 311.8\ \mu$m

c-quark decays

$\Gamma(c \to \ell^+\text{anything})/\Gamma(c \to \text{anything}) = 0.096 \pm 0.004$ [rr]
$\Gamma(c \to D^*(2010)^+\text{anything})/\Gamma(c \to \text{anything}) = 0.255 \pm 0.017$

CP-violation decay-rate asymmetries

$A_{CP}(\mu^\pm\nu) = (8 \pm 8)\%$
$A_{CP}(K_L^0 e^\pm \nu) = (-0.6 \pm 1.6)\%$

$A_{CP}(K_S^0\pi^\pm) = (-0.41 \pm 0.09)\%$
$A_{CP}(K^\mp 2\pi^\pm) = (-0.18 \pm 0.16)\%$
$A_{CP}(K^\mp\pi^\pm\pi^\pm\pi^0) = (-0.3 \pm 0.7)\%$
$A_{CP}(K_S^0\pi^\pm\pi^0) = (-0.1 \pm 0.7)\%$
$A_{CP}(K_S^0\pi^\pm\pi^+\pi^-) = (0.0 \pm 1.2)\%$
$A_{CP}(\pi^\pm\pi^0) = (2.4 \pm 1.2)\%$
$A_{CP}(\pi^\pm\eta) = (1.0 \pm 1.5)\%$ (S = 1.4)
$A_{CP}(\pi^\pm\eta'(958)) = (-0.6 \pm 0.7)\%$
$A_{CP}(\overline{K}^0/K^0K^\pm) = (0.11 \pm 0.17)\%$
$A_{CP}(K_S^0K^\pm) = (-0.11 \pm 0.25)\%$
$A_{CP}(K^+K^-\pi^\pm) = (0.37 \pm 0.29)\%$
$A_{CP}(K^\pm K^{*0}) = (-0.3 \pm 0.4)\%$
$A_{CP}(\phi\pi^\pm) = (0.09 \pm 0.19)\%$ (S = 1.2)
$A_{CP}(K^\pm K_0^*(1430)^0) = (8^{+7}_{-6})\%$
$A_{CP}(K^\pm K_2^*(1430)^0) = (43^{+20}_{-26})\%$
$A_{CP}(K^\pm K_0^*(700)) = (-12^{+18}_{-13})\%$
$A_{CP}(a_0(1450)^0\pi^\pm) = (-19^{+14}_{-16})\%$
$A_{CP}(\phi(1680)\pi^\pm) = (-9 \pm 26)\%$
$A_{CP}(\pi^+\pi^-\pi^\pm) = (-2 \pm 4)\%$
$A_{CP}(K_S^0K^\pm\pi^+\pi^-) = (-4 \pm 7)\%$
$A_{CP}(K^\pm\pi^0) = (-4 \pm 11)\%$

χ^2 tests of *CP*-violation (*CPV*)

Local *CPV* in $D^\pm \to \pi^+\pi^-\pi^\pm = 78.1\%$
Local *CPV* in $D^\pm \to K^+K^-\pi^\pm = 31\%$

CP violating asymmetries of *P*-odd (*T*-odd) moments

$A_T(K_S^0K^\pm\pi^+\pi^-) = (-12 \pm 11) \times 10^{-3}$ [ss]

D^+ form factors

$f_+(0)|V_{cs}|$ in $\overline{K}^0\ell^+\nu_\ell = 0.719 \pm 0.011$ (S = 1.6)
$r_1 \equiv a_1/a_0$ in $\overline{K}^0\ell^+\nu_\ell = -2.13 \pm 0.14$
$r_2 \equiv a_2/a_0$ in $\overline{K}^0\ell^+\nu_\ell = -3 \pm 12$ (S = 1.5)
$f_+(0)|V_{cd}|$ in $\pi^0\ell^+\nu_\ell = 0.1407 \pm 0.0025$
$r_1 \equiv a_1/a_0$ in $\pi^0\ell^+\nu_\ell = -2.00 \pm 0.13$
$r_2 \equiv a_2/a_0$ in $\pi^0\ell^+\nu_\ell = -4 \pm 5$
$f_+(0)|V_{cd}|$ in $D^+ \to \eta e^+\nu_e = 0.086 \pm 0.006$
$r_1 \equiv a_1/a_0$ in $D^+ \to \eta e^+\nu_e = -1.8 \pm 2.2$
$r_v \equiv V(0)/A_1(0)$ in $D^+ \to \omega e^+\nu_e = 1.24 \pm 0.11$
$r_2 \equiv A_2(0)/A_1(0)$ in $D^+ \to \omega e^+\nu_e = 1.06 \pm 0.16$
$r_v \equiv V(0)/A_1(0)$ in $D^+,D^0 \to \rho e^+\nu_e = 1.48 \pm 0.16$
$r_2 \equiv A_2(0)/A_1(0)$ in $D^+,D^0 \to \rho e^+\nu_e = 0.83 \pm 0.12$
$r_v \equiv V(0)/A_1(0)$ in $\overline{K}^*(892)^0\ell^+\nu_\ell = 1.49 \pm 0.05$ (S = 2.1)
$r_2 \equiv A_2(0)/A_1(0)$ in $\overline{K}^*(892)^0\ell^+\nu_\ell = 0.802 \pm 0.021$
$r_3 \equiv A_3(0)/A_1(0)$ in $\overline{K}^*(892)^0\ell^+\nu_\ell = 0.0 \pm 0.4$
Γ_L/Γ_T in $\overline{K}^*(892)^0\ell^+\nu_\ell = 1.13 \pm 0.08$
Γ_+/Γ_- in $\overline{K}^*(892)^0\ell^+\nu_\ell = 0.22 \pm 0.06$ (S = 1.6)

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as K_S^0 modes, not as $\overline{K}^0$ modes. Nearly always it is a K_S^0 that is measured, and interference between Cabibbo-allowed and doubly Cabibbo-suppressed modes can invalidate the assumption that $2\,\Gamma(K_S^0) = \Gamma(\overline{K}^0)$.

D^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Inclusive modes			
e^+ semileptonic	(16.07 ± 0.30) %		–
μ^+ anything	$(17.6\ \pm3.2\ )$ %		–
K^- anything	$(25.7\ \pm1.4\ )$ %		–
$\overline{K}^0$ anything + K^0 anything	$(61\ \pm5\ )$ %		–
K^+ anything	$(\ 5.9\ \pm0.8\ )$ %		–
$K^*(892)^-$ anything	$(\ 6\ \pm5\ )$ %		–
$\overline{K}^*(892)^0$ anything	$(23\ \pm5\ )$ %		–
$K^*(892)^0$ anything	$<\ 6.6$ %	CL=90%	–
η anything	$(\ 6.3\ \pm0.7\ )$ %		–
η' anything	$(\ 1.04\pm0.18)$ %		–
ϕ anything	$(\ 1.03\pm0.12)$ %		–
Leptonic and semileptonic modes			
$e^+\nu_e$	$<\ 8.8 \times 10^{-6}$	CL=90%	935
$\gamma e^+\nu_e$	$<\ 3.0 \times 10^{-5}$	CL=90%	935
$\mu^+\nu_\mu$	$(\ 3.74\pm0.17) \times 10^{-4}$		932
$\tau^+\nu_\tau$	$<\ 1.2 \times 10^{-3}$	CL=90%	90
$\overline{K}^0 e^+\nu_e$	$(\ 8.73\pm0.10)$ %		869
$\overline{K}^0 \mu^+\nu_\mu$	$(\ 8.74\pm0.19)$ %		865
$K^-\pi^+ e^+\nu_e$	$(\ 3.89\pm0.13)$ %	S=2.1	864
$\quad\overline{K}^*(892)^0 e^+\nu_e$, $\overline{K}^*(892)^0 \to K^-\pi^+$	$(\ 3.66\pm0.12)$ %		722
$\quad(K^-\pi^+)_{[0.8\text{–}1.0]\mathrm{GeV}}\, e^+\nu_e$	$(\ 3.39\pm0.09)$ %		864
$\quad(K^-\pi^+)_{S-wave}\, e^+\nu_e$	$(\ 2.28\pm0.11) \times 10^{-3}$		–
$\quad\overline{K}^*(1410)^0 e^+\nu_e$, $\overline{K}^*(1410)^0 \to K^-\pi^+$	$<\ 6 \times 10^{-3}$	CL=90%	–
$\quad\overline{K}_2^*(1430)^0 e^+\nu_e$, $\overline{K}_2^*(1430)^0 \to K^-\pi^+$	$<\ 5 \times 10^{-4}$	CL=90%	–
$\quad K^-\pi^+ e^+\nu_e$ nonresonant	$<\ 7 \times 10^{-3}$	CL=90%	864
$K^-\pi^+\mu^+\nu_\mu$	$(\ 3.65\pm0.34)$ %		851
$\quad\overline{K}^*(892)^0 \mu^+\nu_\mu$, $\overline{K}^*(892)^0 \to K^-\pi^+$	$(\ 3.52\pm0.10)$ %		717
$\quad K^-\pi^+\mu^+\nu_\mu$ nonresonant	$(\ 1.9\ \pm0.5\ ) \times 10^{-3}$		851
$K^-\pi^+\pi^0\mu^+\nu_\mu$	$<\ 1.5 \times 10^{-3}$	CL=90%	825
$\pi^0 e^+\nu_e$	$(\ 3.72\pm0.17) \times 10^{-3}$	S=2.0	930
$\eta e^+\nu_e$	$(\ 1.14\pm0.10) \times 10^{-3}$		855
$\rho^0 e^+\nu_e$	$(\ 2.18^{+0.17}_{-0.25}) \times 10^{-3}$		774
$\rho^0 \mu^+\nu_\mu$	$(\ 2.4\ \pm0.4\ ) \times 10^{-3}$		770
$\omega e^+\nu_e$	$(\ 1.69\pm0.11) \times 10^{-3}$		771
$\eta'(958) e^+\nu_e$	$(\ 2.2\ \pm0.5\ ) \times 10^{-4}$		690
$\phi e^+\nu_e$	$<\ 1.3 \times 10^{-5}$	CL=90%	657
$D^0 e^+\nu_e$	$<\ 1.0 \times 10^{-4}$	CL=90%	5

Fractions of some of the following modes with resonances have already appeared above as submodes of particular charged-particle modes.

$\overline{K}^*(892)^0 e^+\nu_e$	$(\ 5.40\pm0.10)$ %	S=1.1	722
$\overline{K}^*(892)^0 \mu^+\nu_\mu$	$(\ 5.25\pm0.15)$ %		717
$\overline{K}_0^*(1430)^0 \mu^+\nu_\mu$	$<\ 2.3 \times 10^{-4}$	CL=90%	380
$\overline{K}^*(1680)^0 \mu^+\nu_\mu$	$<\ 1.5 \times 10^{-3}$	CL=90%	105

Hadronic modes with a $\overline{K}$ or $\overline{K}K\overline{K}$

$K^0_S\pi^+$		(1.47 ± 0.08) %	S=3.0	863
$K^0_L\pi^+$		(1.46 ± 0.05) %		863
$K^-2\pi^+$	[tt]	(8.98 ± 0.28) %	S=2.2	846
$(K^-\pi^+)_{S-\text{wave}}\pi^+$		(7.20 ± 0.25) %		846
$\overline{K}^*_0(1430)^0\pi^+$, $\overline{K}^*_0(1430)^0 \to K^-\pi^+$	[uu]	(1.19 ± 0.07) %		382
$\overline{K}^*(892)^0\pi^+$, $\overline{K}^*(892)^0 \to K^-\pi^+$		$(10.0\ \pm1.1\ )\times10^{-3}$		714
$\overline{K}^*_2(1430)^0\pi^+$, $\overline{K}^*_2(1430)^0 \to K^-\pi^+$	[uu]	$(2.2\ \pm0.7\ )\times10^{-4}$		371
$\overline{K}^*(1680)^0\pi^+$, $\overline{K}^*(1680)^0 \to K^-\pi^+$	[uu]	$(2.1\ \pm1.0\ )\times10^{-4}$		58
$K^-(2\pi^+)_{I=2}$		(1.39 ± 0.26) %		–
$K^0_S\pi^+\pi^0$	[tt]	(7.05 ± 0.27) %		845
$K^0_S\rho^+$		$(5.9\ ^{+0.6}_{-0.4}\ )$ %		677
$K^0_S\rho(1450)^+$, $\rho^+ \to \pi^+\pi^0$		$(1.5\ ^{+1.1}_{-1.4}\ )\times10^{-3}$		–
$\overline{K}^*(892)^0\pi^+$, $\overline{K}^*(892)^0 \to K^0_S\pi^0$		$(2.52\pm0.31)\times10^{-3}$		714
$\overline{K}^*_0(1430)^0\pi^+$, $\overline{K}^{*0}_0 \to K^0_S\pi^0$		$(2.6\ \pm0.9\ )\times10^{-3}$		–
$\overline{K}^*_0(1680)^0\pi^+$, $\overline{K}^{*0}_0 \to K^0_S\pi^0$		$(9\ \ ^{+7}_{-9}\ )\times10^{-4}$		–
$\overline{\kappa}^0\pi^+$, $\overline{\kappa}^0 \to K^0_S\pi^0$		$(5.4\ ^{+5.0}_{-3.5}\ )\times10^{-3}$		–
$K^0_S\pi^+\pi^0$ nonresonant		$(3\ \ \pm4\ \ )\times10^{-3}$		845
$K^0_S\pi^+\pi^0$ nonresonant and $\overline{\kappa}^0\pi^+$		$(1.31^{+0.21}_{-0.35})$ %		–
$(K^0_S\pi^0)_{S-\text{wave}}\pi^+$		$(1.22^{+0.26}_{-0.32})$ %		845
$K^-2\pi^+\pi^0$	[vv]	(5.98 ± 0.23) %		816
$K^0_S2\pi^+\pi^-$	[vv]	(2.97 ± 0.11) %		814
$K^-3\pi^+\pi^-$	[tt]	$(5.5\ \pm0.5\ )\times10^{-3}$	S=1.1	772
$\overline{K}^*(892)^02\pi^+\pi^-$, $\overline{K}^*(892)^0 \to K^-\pi^+$		$(1.2\ \pm0.4\ )\times10^{-3}$		645
$\overline{K}^*(892)^0\rho^0\pi^+$, $\overline{K}^*(892)^0 \to K^-\pi^+$		$(2.2\ \pm0.4\ )\times10^{-3}$		239
$\overline{K}^*(892)^0a_1(1260)^+$	[xx]	$(8.9\ \pm1.8\ )\times10^{-3}$		†
$K^-\rho^02\pi^+$		$(1.65\pm0.27)\times10^{-3}$		524
$K^-3\pi^+\pi^-$ nonresonant		$(3.9\ \pm2.8\ )\times10^{-4}$		772
$K^+2K^0_S$		$(2.54\pm0.13)\times10^{-3}$		545
$K^+K^-K^0_S\pi^+$		$(2.3\ \pm0.5\ )\times10^{-4}$		436

Pionic modes

$\pi^+\pi^0$		$(1.17\pm0.06)\times10^{-3}$		925
$2\pi^+\pi^-$		$(3.13\pm0.19)\times10^{-3}$		909
$\rho^0\pi^+$		$(8.0\ \pm1.4\ )\times10^{-4}$		767
$\pi^+(\pi^+\pi^-)_{S-\text{wave}}$		$(1.75\pm0.16)\times10^{-3}$		909
$\sigma\pi^+$, $\sigma \to \pi^+\pi^-$		$(1.32\pm0.12)\times10^{-3}$		–
$f_0(980)\pi^+$, $f_0(980) \to \pi^+\pi^-$		$(1.50\pm0.32)\times10^{-4}$		669
$f_0(1370)\pi^+$, $f_0(1370) \to \pi^+\pi^-$		$(8\ \ \pm4\ \ )\times10^{-5}$		–
$f_2(1270)\pi^+$, $f_2(1270) \to \pi^+\pi^-$		$(4.8\ \pm0.8\ )\times10^{-4}$		485

$\rho(1450)^0\pi^+$, $\rho(1450)^0 \to \pi^+\pi^-$	$< 8 \times 10^{-5}$		CL=95%	338
$f_0(1500)\pi^+$, $f_0(1500) \to \pi^+\pi^-$	$(1.1 \pm 0.4) \times 10^{-4}$			–
$f_0(1710)\pi^+$, $f_0(1710) \to \pi^+\pi^-$	$< 5 \times 10^{-5}$		CL=95%	–
$f_0(1790)\pi^+$, $f_0(1790) \to \pi^+\pi^-$	$< 6 \times 10^{-5}$		CL=95%	–
$(\pi^+\pi^+)_{S-\text{wave}}\pi^-$	$< 1.2 \times 10^{-4}$		CL=95%	909
$2\pi^+\pi^-$ nonresonant	$< 1.1 \times 10^{-4}$		CL=95%	909
$\pi^+2\pi^0$	$(4.5 \pm 0.4) \times 10^{-3}$			910
$2\pi^+\pi^-\pi^0$	(1.11 ± 0.08) %			883
$3\pi^+2\pi^-$	$(1.59 \pm 0.16) \times 10^{-3}$		S=1.1	845
$\eta\pi^+$	$(3.33 \pm 0.21) \times 10^{-3}$		S=1.4	848
$\eta\pi^+\pi^0$	$(1.38 \pm 0.35) \times 10^{-3}$			831
$\omega\pi^+$	$(2.8 \pm 0.6) \times 10^{-4}$			764
$\eta'(958)\pi^+$	$(4.60 \pm 0.31) \times 10^{-3}$			681
$\eta'(958)\pi^+\pi^0$	$(1.6 \pm 0.5) \times 10^{-3}$			654
Hadronic modes with a $K\overline{K}$ pair				
$K^+K^0_S$	$(2.83 \pm 0.16) \times 10^{-3}$		S=2.8	793
$K^+K^-\pi^+$	[tt] $(9.51 \pm 0.34) \times 10^{-3}$		S=1.6	744
$\phi\pi^+$, $\phi \to K^+K^-$	$(2.64 \pm 0.11) \times 10^{-3}$			647
$K^+\overline{K}^*(892)^0$, $\overline{K}^*(892)^0 \to K^-\pi^+$	$(2.44^{+0.11}_{-0.15}) \times 10^{-3}$			613
$K^+\overline{K}^*_0(1430)^0$, $\overline{K}^*_0(1430)^0 \to K^-\pi^+$	$(1.79 \pm 0.34) \times 10^{-3}$			–
$K^+\overline{K}^*_2(1430)^0$, $\overline{K}^*_2 \to K^-\pi^+$	$(1.6^{+1.2}_{-0.8}) \times 10^{-4}$			–
$K^+\overline{K}^*_0(700)$, $\overline{K}^*_0 \to K^-\pi^+$	$(6.7^{+3.4}_{-2.1}) \times 10^{-4}$			–
$a_0(1450)^0\pi^+$, $a^0_0 \to K^+K^-$	$(4.4^{+7.0}_{-1.8}) \times 10^{-4}$			–
$\phi(1680)\pi^+$, $\phi \to K^+K^-$	$(4.9^{+4.0}_{-1.9}) \times 10^{-5}$			–
$K^0_SK^0_S\pi^+$	$(2.70 \pm 0.13) \times 10^{-3}$			741
$K^+K^0_S\pi^+\pi^-$	$(1.67 \pm 0.18) \times 10^{-3}$			678
$K^0_SK^-2\pi^+$	$(2.28 \pm 0.18) \times 10^{-3}$			678
$K^+K^-2\pi^+\pi^-$	$(2.2 \pm 1.2) \times 10^{-4}$			601
A few poorly measured branching fractions:				
$\phi\pi^+\pi^0$	(2.3 ± 1.0) %			619
$\phi\rho^+$	< 1.4 %		CL=90%	260
$K^+K^-\pi^+\pi^0$ non-ϕ	$(1.5^{+0.7}_{-0.6})$ %			682
$K^*(892)^+K^0_S$	(1.6 ± 0.7) %			611
Doubly Cabibbo-suppressed modes				
$K^+\pi^0$	$(1.81 \pm 0.27) \times 10^{-4}$		S=1.4	864
$K^+\eta$	$(1.02 \pm 0.16) \times 10^{-4}$			776
$K^+\eta'(958)$	$(1.73 \pm 0.22) \times 10^{-4}$			571
$K^+\pi^+\pi^-$	$(5.19 \pm 0.26) \times 10^{-4}$			846
$K^+\rho^0$	$(2.0 \pm 0.5) \times 10^{-4}$			679
$K^*(892)^0\pi^+$, $K^*(892)^0 \to K^+\pi^-$	$(2.4 \pm 0.4) \times 10^{-4}$			714
$K^+f_0(980)$, $f_0(980) \to \pi^+\pi^-$	$(4.6 \pm 2.8) \times 10^{-5}$			–

$K_2^*(1430)^0\pi^+$, $K_2^*(1430)^0 \to K^+\pi^-$				$(4.2 \pm 2.8) \times 10^{-5}$		–
$2K^+K^-$				$(8.5 \pm 2.0) \times 10^{-5}$		550

$\Delta C = 1$ weak neutral current (*C1*) modes, or Lepton Family number (*LF*) or Lepton number (*L*) violating modes

$\pi^+e^+e^-$	C1		<	1.1×10^{-6}	CL=90%	930
$\pi^+\phi$, $\phi \to e^+e^-$		[yy]		$(1.7\ ^{+1.4}_{-0.9}) \times 10^{-6}$		–
$\pi^+\mu^+\mu^-$	C1		<	7.3×10^{-8}	CL=90%	918
$\pi^+\phi$, $\phi \to \mu^+\mu^-$		[yy]		$(1.8 \pm 0.8) \times 10^{-6}$		–
$\rho^+\mu^+\mu^-$	C1		<	5.6×10^{-4}	CL=90%	757
$K^+e^+e^-$		[zz]	<	1.0×10^{-6}	CL=90%	870
$K^+\mu^+\mu^-$		[zz]	<	4.3×10^{-6}	CL=90%	856
$\pi^+e^+\mu^-$	LF		<	2.9×10^{-6}	CL=90%	927
$\pi^+e^-\mu^+$	LF		<	3.6×10^{-6}	CL=90%	927
$K^+e^+\mu^-$	LF		<	1.2×10^{-6}	CL=90%	866
$K^+e^-\mu^+$	LF		<	2.8×10^{-6}	CL=90%	866
π^-2e^+	L		<	1.1×10^{-6}	CL=90%	930
$\pi^-2\mu^+$	L		<	2.2×10^{-8}	CL=90%	918
$\pi^-e^+\mu^+$	L		<	2.0×10^{-6}	CL=90%	927
$\rho^-2\mu^+$	L		<	5.6×10^{-4}	CL=90%	757
K^-2e^+	L		<	9×10^{-7}	CL=90%	870
$K^-2\mu^+$	L		<	1.0×10^{-5}	CL=90%	856
$K^-e^+\mu^+$	L		<	1.9×10^{-6}	CL=90%	866
$K^*(892)^-2\mu^+$	L		<	8.5×10^{-4}	CL=90%	703

See Particle Listings for 2 decay modes that have been seen / not seen.

D^0

$I(J^P) = \frac{1}{2}(0^-)$

Mass $m = 1864.83 \pm 0.05$ MeV

$m_{D^\pm} - m_{D^0} = 4.822 \pm 0.015$ MeV

Mean life $\tau = (410.1 \pm 1.5) \times 10^{-15}$ s

$c\tau = 122.9\ \mu$m

Mixing and related parameters

$\left|m_{D_1^0} - m_{D_2^0}\right| = (0.95^{+0.41}_{-0.44}) \times 10^{10}\ \hbar\ \mathrm{s}^{-1}$

$(\Gamma_{D_1^0} - \Gamma_{D_2^0})/\Gamma = 2y = (1.29^{+0.14}_{-0.18}) \times 10^{-2}$

$\left|q/p\right| = 0.92^{+0.12}_{-0.09}$

$A_\Gamma = (-0.125 \pm 0.526) \times 10^{-3}$

$K^+\pi^-$ relative strong phase: $\cos\delta = 0.97 \pm 0.11$

$K^-\pi^+\pi^0$ coherence factor $R_{K\pi\pi^0} = 0.82 \pm 0.06$

$K^-\pi^+\pi^0$ average relative strong phase $\delta^{K\pi\pi^0} = (199 \pm 14)^\circ$

$K^-\pi^-2\pi^+$ coherence factor $R_{K3\pi} = 0.53^{+0.18}_{-0.21}$

$K^-\pi^-2\pi^+$ average relative strong phase $\delta^{K3\pi} = (125^{+22}_{-14})^\circ$

$D^0 \to K^-\pi^-2\pi^+$, $R_{K3\pi}$ (y $\cos\delta^{K3\pi}$ – x $\sin\delta^{K3\pi}$) $= (-3.0 \pm 0.7) \times 10^{-3}\ \mathrm{TeV}^{-1}$

$K_S^0K^+\pi^-$ coherence factor $R_{K_S^0K\pi} = 0.70 \pm 0.08$

$K_S^0K^+\pi^-$ average relative strong phase $\delta^{K_S^0K\pi} = (0 \pm 16)^\circ$

K^*K coherence factor $R_{K^*K} = 0.94 \pm 0.12$

K^*K average relative strong phase $\delta^{K^*K} = (-17 \pm 18)^\circ$

CP-violation decay-rate asymmetries (labeled by the D^0 decay)

$A_{CP}(K^+ K^-) = (-0.07 \pm 0.11)\%$
$A_{CP}(2K^0_S) = (-0.4 \pm 1.5)\%$
$A_{CP}(\pi^+ \pi^-) = (0.13 \pm 0.14)\%$
$A_{CP}(\pi^0 \pi^0) = (0.0 \pm 0.6)\%$
$A_{CP}(\rho\gamma) = (6 \pm 15) \times 10^{-2}$
$A_{CP}(\phi\gamma) = (-9 \pm 7) \times 10^{-2}$
$A_{CP}(\overline{K}^*(892)^0 \gamma) = (-0.3 \pm 2.0) \times 10^{-2}$
$A_{CP}(\pi^+ \pi^- \pi^0) = (0.3 \pm 0.4)\%$
$A_{CP}(\rho(770)^+ \pi^- \to \pi^+ \pi^- \pi^0) = (1.2 \pm 0.9)\%$ [aaa]
$A_{CP}(\rho(770)^0 \pi^0 \to \pi^+ \pi^- \pi^0) = (-3.1 \pm 3.0)\%$ [aaa]
$A_{CP}(\rho(770)^- \pi^+ \to \pi^+ \pi^- \pi^0) = (-1.0 \pm 1.7)\%$ [aaa]
$A_{CP}(\rho(1450)^+ \pi^- \to \pi^+ \pi^- \pi^0) = (0 \pm 70)\%$ [aaa]
$A_{CP}(\rho(1450)^0 \pi^0 \to \pi^+ \pi^- \pi^0) = (-20 \pm 40)\%$ [aaa]
$A_{CP}(\rho(1450)^- \pi^+ \to \pi^+ \pi^- \pi^0) = (6 \pm 9)\%$ [aaa]
$A_{CP}(\rho(1700)^+ \pi^- \to \pi^+ \pi^- \pi^0) = (-5 \pm 14)\%$ [aaa]
$A_{CP}(\rho(1700)^0 \pi^0 \to \pi^+ \pi^- \pi^0) = (13 \pm 9)\%$ [aaa]
$A_{CP}(\rho(1700)^- \pi^+ \to \pi^+ \pi^- \pi^0) = (8 \pm 11)\%$ [aaa]
$A_{CP}(f_0(980) \pi^0 \to \pi^+ \pi^- \pi^0) = (0 \pm 35)\%$ [aaa]
$A_{CP}(f_0(1370) \pi^0 \to \pi^+ \pi^- \pi^0) = (25 \pm 18)\%$ [aaa]
$A_{CP}(f_0(1500) \pi^0 \to \pi^+ \pi^- \pi^0) = (0 \pm 18)\%$ [aaa]
$A_{CP}(f_0(1710) \pi^0 \to \pi^+ \pi^- \pi^0) = (0 \pm 24)\%$ [aaa]
$A_{CP}(f_2(1270) \pi^0 \to \pi^+ \pi^- \pi^0) = (-4 \pm 6)\%$ [aaa]
$A_{CP}(\sigma(400) \pi^0 \to \pi^+ \pi^- \pi^0) = (6 \pm 8)\%$ [aaa]
$A_{CP}(\text{nonresonant } \pi^+ \pi^- \pi^0) = (-13 \pm 23)\%$ [aaa]
$A_{CP}(a_1(1260)^+ \pi^- \to 2\pi^+ 2\pi^-) = (5 \pm 6)\%$
$A_{CP}(a_1(1260)^- \pi^+ \to 2\pi^+ 2\pi^-) = (14 \pm 18)\%$
$A_{CP}(\pi(1300)^+ \pi^- \to 2\pi^+ 2\pi^-) = (-2 \pm 15)\%$
$A_{CP}(\pi(1300)^- \pi^+ \to 2\pi^+ 2\pi^-) = (-6 \pm 30)\%$
$A_{CP}(a_1(1640)^+ \pi^- \to 2\pi^+ 2\pi^-) = (9 \pm 26)\%$
$A_{CP}(\pi_2(1670)^+ \pi^- \to 2\pi^+ 2\pi^-) = (7 \pm 18)\%$
$A_{CP}(\sigma f_0(1370) \to 2\pi^+ 2\pi^-) = (-15 \pm 19)\%$
$A_{CP}(\sigma \rho(770)^0 \to 2\pi^+ 2\pi^-) = (3 \pm 27)\%$
$A_{CP}(2\rho(770)^0 \to 2\pi^+ 2\pi^-) = (-6 \pm 6)\%$
$A_{CP}(2f_2(1270) \to 2\pi^+ 2\pi^-) = (-28 \pm 24)\%$
$A_{CP}(K^+ K^- \pi^0) = (-1.0 \pm 1.7)\%$
$A_{CP}(K^*(892)^+ K^- \to K^+ K^- \pi^0) = (-0.9 \pm 1.3)\%$ [aaa]
$A_{CP}(K^*(1410)^+ K^- \to K^+ K^- \pi^0) = (-21 \pm 24)\%$ [aaa]
$A_{CP}((K^+ \pi^0)_{S-wave} K^- \to K^+ K^- \pi^0) = (7 \pm 15)\%$ [aaa]
$A_{CP}(\phi(1020) \pi^0 \to K^+ K^- \pi^0) = (1.1 \pm 2.2)\%$ [aaa]
$A_{CP}(f_0(980) \pi^0 \to K^+ K^- \pi^0) = (-3 \pm 19)\%$ [aaa]
$A_{CP}(a_0(980)^0 \pi^0 \to K^+ K^- \pi^0) = (-5 \pm 16)\%$ [aaa]
$A_{CP}(f'_2(1525) \pi^0 \to K^+ K^- \pi^0) = (0 \pm 160)\%$ [aaa]
$A_{CP}(K^*(892)^- K^+ \to K^+ K^- \pi^0) = (-5 \pm 4)\%$ [aaa]
$A_{CP}(K^*(1410)^- K^+ \to K^+ K^- \pi^0) = (-17 \pm 29)\%$ [aaa]
$A_{CP}((K^- \pi^0)_{S-wave} K^+ \to K^+ K^- \pi^0) = (-10 \pm 40)\%$ [aaa]
$A_{CP}(K^0_S \pi^0) = (-0.20 \pm 0.17)\%$
$A_{CP}(K^0_S \eta) = (0.5 \pm 0.5)\%$
$A_{CP}(K^0_S \eta') = (1.0 \pm 0.7)\%$
$A_{CP}(K^0_S \phi) = (-3 \pm 9)\%$
$A_{CP}(K^- \pi^+) = (0.3 \pm 0.7)\%$

$A_{CP}(K^+\pi^-) = (-0.9 \pm 1.4)\%$
$A_{CP}(D_{CP(\pm1)} \to K^\mp\pi^\pm) = (12.7 \pm 1.5)\%$
$A_{CP}(K^-\pi^+\pi^0) = (0.1 \pm 0.5)\%$
$A_{CP}(K^+\pi^-\pi^0) = (0 \pm 5)\%$
$A_{CP}(K^0_S\pi^+\pi^-) = (-0.1 \pm 0.8)\%$
$A_{CP}(K^*(892)^-\pi^+ \to K^0_S\pi^+\pi^-) = (0.4 \pm 0.5)\%$
$A_{CP}(K^*(892)^+\pi^- \to K^0_S\pi^+\pi^-) = (1 \pm 6)\%$
$A_{CP}(\overline{K}^0\rho^0 \to K^0_S\pi^+\pi^-) = (-0.1 \pm 0.5)\%$
$A_{CP}(\overline{K}^0\omega \to K^0_S\pi^+\pi^-) = (-13 \pm 7)\%$
$A_{CP}(\overline{K}^0 f_0(980) \to K^0_S\pi^+\pi^-) = (-0.4 \pm 2.7)\%$
$A_{CP}(\overline{K}^0 f_2(1270) \to K^0_S\pi^+\pi^-) = (-4 \pm 5)\%$
$A_{CP}(\overline{K}^0 f_0(1370) \to K^0_S\pi^+\pi^-) = (-1 \pm 9)\%$
$A_{CP}(\overline{K}^0\rho^0(1450) \to K^0_S\pi^+\pi^-) = (-4 \pm 10)\%$
$A_{CP}(\overline{K}^0 f_0(600) \to K^0_S\pi^+\pi^-) = (-3 \pm 5)\%$
$A_{CP}(K^*(1410)^-\pi^+ \to K^0_S\pi^+\pi^-) = (-2 \pm 9)\%$
$A_{CP}(K^*_0(1430)^-\pi^+ \to K^0_S\pi^+\pi^-) = (4 \pm 4)\%$
$A_{CP}(K^*_0(1430)^+\pi^- \to K^0_S\pi^+\pi^-) = (12 \pm 15)\%$
$A_{CP}(K^*_2(1430)^-\pi^+ \to K^0_S\pi^+\pi^-) = (3 \pm 6)\%$
$A_{CP}(K^*_2(1430)^+\pi^- \to K^0_S\pi^+\pi^-) = (-10 \pm 32)\%$
$A_{CP}(K^-\pi^+\pi^+\pi^-) = (0.2 \pm 0.5)\%$
$A_{CP}(K^+\pi^-\pi^+\pi^-) = (-2 \pm 4)\%$
$A_{CP}(K^+K^-\pi^+\pi^-) = (1.3 \pm 1.7)\%$
$A_{CP}(K^*_1(1270)^+K^- \to K^+K^-\pi^+\pi^-) = (25 \pm 16)\%$
$A_{CP}(K^*_1(1270)^+K^- \to K^{*0}\pi^+K^-) = (-1 \pm 10)\%$
$A_{CP}(K^*_1(1270)^-K^+ \to \overline{K}^{*0}\pi^-K^+) = (-10 \pm 32)\%$
$A_{CP}(K^*_1(1270)^-K^+ \to K^+K^-\pi^+\pi^-) = (-50 \pm 20)\%$
$A_{CP}(K^*_1(1270)^+K^- \to \rho^0K^+K^-) = (-7 \pm 17)\%$
$A_{CP}(K^*_1(1270)^-K^+ \to \rho^0K^-K^+) = (10 \pm 13)\%$
$A_{CP}(K^*_1(1400)^+K^- \to K^+K^-\pi^+\pi^-) = (9 \pm 25)\%$
$A_{CP}(K^*(1410)^+K^- \to K^{*0}\pi^+K^-) = (-20 \pm 17)\%$
$A_{CP}(K^*(1410)^-K^+ \to \overline{K}^{*0}\pi^-K^+) = (-1 \pm 14)\%$
$A_{CP}(K^*(1680)^+K^- \to K^+K^-\pi^+\pi^-) = (-17 \pm 29)\%$
$A_{CP}(K^{*0}\overline{K}^{*0})$ in $D^0, \overline{D}^0 \to K^{*0}\overline{K}^{*0} = (-5 \pm 14)\%$
$A_{CP}(K^{*0}\overline{K}^{*0}$ S-wave$) = (10 \pm 14)\%$
$A_{CP}(\phi\rho^0)$ in $D^0, \overline{D}^0 \to \phi\rho^0 = (1 \pm 9)\%$
$A_{CP}(\phi\rho^0$ S-wave$) = (-3 \pm 5)\%$
$A_{CP}(\phi\rho^0$ D-wave$) = (-37 \pm 19)\%$
$A_{CP}(\phi(\pi^+\pi^-)_{S-wave}) = (0 \pm 50)\%$
$A_{CP}(K^*(892)^0(K^-\pi^+)_{S-wave}) = (-10 \pm 40)\%$
$A_{CP}(K^+K^-\pi^+\pi^-$ non-resonant$) = (8 \pm 20)\%$
$A_{CP}((K^-\pi^+)_{P-wave}\,(K^+\pi^-)_{S-wave}) = (3 \pm 11)\%$

CP-even fractions (labeled by the D^0 decay)

CP-even fraction in $D^0 \to \pi^+\pi^-\pi^0$ decays $= (97.3 \pm 1.7)\%$
CP-even fraction in $D^0 \to K^+K^-\pi^0$ decays $= (73 \pm 6)\%$
CP-even fraction in $D^0 \to \pi^+\pi^-\pi^+\pi^-$ decays $= (73.7 \pm 2.8)\%$
CP-even fraction in $D^0 \to K^+K^-\pi^+\pi^-$ decays $= (75 \pm 4)\%$

CP-violation asymmetry difference

$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-0.12 \pm 0.13)\%$ (S = 1.8)

χ^2 tests of *CP*-violation (*CPV*)

Local *CPV* in D^0, $\overline{D}^0 \to \pi^+\pi^-\pi^0 = 4.9\%$
Local *CPV* in D^0, $\overline{D}^0 \to \pi^+\pi^-\pi^+\pi^- = (0.6 \pm 0.2)\%$
Local *CPV* in D^0, $\overline{D}^0 \to K^0_S\pi^+\pi^- = 96\%$
Local *CPV* in D^0, $\overline{D}^0 \to K^+K^-\pi^0 = 16.6\%$
Local *CPV* in D^0, $\overline{D}^0 \to K^+K^-\pi^+\pi^- = 9.1\%$

T-violation decay-rate asymmetry

$A_T(K^+K^-\pi^+\pi^-) = (1.7 \pm 2.7) \times 10^{-3}$ [ss]
$A_{\text{Tviol}}(K_S\pi^+\pi^-\pi^0)$ in D^0, $\overline{D}^0 \to K_S\pi^+\pi^-\pi^0 = (-0.3^{+1.4}_{-1.6}) \times 10^{-3}$

CPT-violation decay-rate asymmetry

$A_{CPT}(K^\mp\pi^\pm) = 0.008 \pm 0.008$

Form factors

$\mathrm{r}_V \equiv \mathrm{V}(0)/\mathrm{A}_1(0)$ in $D^0 \to K^*(892)^-\ell^+\nu_\ell = 1.7 \pm 0.8$
$\mathrm{r}_2 \equiv \mathrm{A}_2(0)/\mathrm{A}_1(0)$ in $D^0 \to K^*(892)^-\ell^+\nu_\ell = 0.9 \pm 0.4$
$f_+(0)$ in $D^0 \to K^-\ell^+\nu_\ell = 0.736 \pm 0.004$
$f_+(0)|V_{cs}|$ in $D^0 \to K^-\ell^+\nu_\ell = 0.719 \pm 0.004$
$r_1 \equiv a_1/a_0$ in $D^0 \to K^-\ell^+\nu_\ell = -2.40 \pm 0.16$
$r_2 \equiv a_2/a_0$ in $D^0 \to K^-\ell^+\nu_\ell = 5 \pm 4$
$f_+(0)$ in $D^0 \to \pi^-\ell^+\nu_\ell = 0.637 \pm 0.009$
$f_+(0)|V_{cd}|$ in $D^0 \to \pi^-\ell^+\nu_\ell = 0.1436 \pm 0.0026$ (S = 1.5)
$r_1 \equiv a_1/a_0$ in $D^0 \to \pi^-\ell^+\nu_\ell = -1.97 \pm 0.28$ (S = 1.4)
$r_2 \equiv a_1/a_0$ in $D^0 \to \pi^-\ell^+\nu_\ell = -0.2 \pm 2.2$ (S = 1.7)

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as K^0_S modes, not as $\overline{K}^0$ modes. Nearly always it is a K^0_S that is measured, and interference between Cabibbo-allowed and doubly Cabibbo-suppressed modes can invalidate the assumption that $2\,\Gamma(K^0_S) = \Gamma(\overline{K}^0)$.

D^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Topological modes				
0-prongs	[bbb]	$(15 \pm 6)\%$		–
2-prongs		$(70 \pm 6)\%$		–
4-prongs	[ccc]	$(14.5 \pm 0.5)\%$		–
6-prongs	[ddd]	$(6.4 \pm 1.3) \times 10^{-4}$		–
Inclusive modes				
e^+ anything	[eee]	$(6.49 \pm 0.11)\%$		–
μ^+ anything		$(6.7 \pm 0.6)\%$		–
K^- anything		$(54.7 \pm 2.8)\%$	S=1.3	–
$\overline{K}^0$ anything + K^0 anything		$(47 \pm 4)\%$		–
K^+ anything		$(3.4 \pm 0.4)\%$		–
$K^*(892)^-$ anything		$(15 \pm 9)\%$		–
$\overline{K}^*(892)^0$ anything		$(9 \pm 4)\%$		–
$K^*(892)^+$ anything		$< 3.6\%$	CL=90%	–
$K^*(892)^0$ anything		$(2.8 \pm 1.3)\%$		–
η anything		$(9.5 \pm 0.9)\%$		–
η' anything		$(2.48 \pm 0.27)\%$		–
ϕ anything		$(1.05 \pm 0.11)\%$		–
invisibles		$< 9.4 \times 10^{-5}$	CL=90%	–

Semileptonic modes

$K^- e^+ \nu_e$		(3.530 ± 0.028) %	S=1.1	867
$K^- \mu^+ \nu_\mu$		(3.31 ± 0.13) %		864
$K^*(892)^- e^+ \nu_e$		(2.15 ± 0.16) %		719
$K^*(892)^- \mu^+ \nu_\mu$		(1.86 ± 0.24) %		714
$K^- \pi^0 e^+ \nu_e$		$(1.6 {}^{+1.3}_{-0.5})$ %		861
$\overline{K}^0 \pi^- e^+ \nu_e$		$(2.7 {}^{+0.9}_{-0.7})$ %		860
$K^- \pi^+ \pi^- e^+ \nu_e$		$(2.8 {}^{+1.4}_{-1.1}) \times 10^{-4}$		843
$K_1(1270)^- e^+ \nu_e$		$(7.6 {}^{+4.0}_{-3.1}) \times 10^{-4}$		498
$K^- \pi^+ \pi^- \mu^+ \nu_\mu$		$< 1.2 \times 10^{-3}$	CL=90%	821
$(\overline{K}^*(892)\pi)^- \mu^+ \nu_\mu$		$< 1.4 \times 10^{-3}$	CL=90%	692
$\pi^- e^+ \nu_e$		$(2.91 \pm 0.04) \times 10^{-3}$	S=1.1	927
$\pi^- \mu^+ \nu_\mu$		$(2.37 \pm 0.24) \times 10^{-3}$		924
$\rho^- e^+ \nu_e$		$(1.77 \pm 0.16) \times 10^{-3}$		771

Hadronic modes with one $\overline{K}$

$K^- \pi^+$		(3.89 ± 0.04) %	S=1.1	861
$K^0_S \pi^0$		(1.19 ± 0.04) %		860
$K^0_L \pi^0$		$(10.0 \pm 0.7) \times 10^{-3}$		860
$K^0_S \pi^+ \pi^-$	[tt]	(2.75 ± 0.18) %	S=1.1	842
$K^0_S \rho^0$		$(6.2 {}^{+0.6}_{-0.8}) \times 10^{-3}$		674
$K^0_S \omega,\ \omega \to \pi^+\pi^-$		$(2.0 \pm 0.6) \times 10^{-4}$		670
$K^0_S (\pi^+\pi^-)_{S-wave}$		$(3.3 \pm 0.7) \times 10^{-3}$		842
$K^0_S f_0(980),\ f_0 \to \pi^+\pi^-$		$(1.18 {}^{+0.40}_{-0.23}) \times 10^{-3}$		549
$K^0_S f_0(1370),\ f_0 \to \pi^+\pi^-$		$(2.7 {}^{+0.8}_{-1.3}) \times 10^{-3}$		†
$K^0_S f_2(1270),\ f_2 \to \pi^+\pi^-$		$(9 {}^{+10}_{-6}) \times 10^{-5}$		262
$K^*(892)^- \pi^+,\ K^{*-} \to K^0_S \pi^-$		$(1.62 {}^{+0.14}_{-0.17})$ %		711
$K^*_0(1430)^- \pi^+,\ K^{*-}_0 \to K^0_S \pi^-$		$(2.63 {}^{+0.40}_{-0.32}) \times 10^{-3}$		378
$K^*_2(1430)^- \pi^+,\ K^{*-}_2 \to K^0_S \pi^-$		$(3.3 {}^{+1.8}_{-1.0}) \times 10^{-4}$		367
$K^*(1680)^- \pi^+,\ K^{*-} \to K^0_S \pi^-$		$(4.3 \pm 3.5) \times 10^{-4}$		46
$K^*(892)^+ \pi^-,\ K^{*+} \to K^0_S \pi^+$	[fff]	$(1.11 {}^{+0.60}_{-0.33}) \times 10^{-4}$		711
$K^*_0(1430)^+ \pi^-,\ K^{*+}_0 \to K^0_S \pi^+$	[fff]	$< 1.4 \times 10^{-5}$	CL=95%	–
$K^*_2(1430)^+ \pi^-,\ K^{*+}_2 \to K^0_S \pi^+$	[fff]	$< 3.3 \times 10^{-5}$	CL=95%	–
$K^0_S \pi^+ \pi^-$ nonresonant		$(2.5 {}^{+6.0}_{-1.6}) \times 10^{-4}$		842
$K^- \pi^+ \pi^0$	[tt]	(14.2 ± 0.5) %	S=1.9	844
$K^- \rho^+$		(11.1 ± 0.7) %		675
$K^- \rho(1700)^+,\ \rho^+ \to \pi^+\pi^0$		$(8.1 \pm 1.7) \times 10^{-3}$		†
$K^*(892)^- \pi^+,\ K^*(892)^- \to K^- \pi^0$		$(2.27 {}^{+0.40}_{-0.20})$ %		711

$\overline{K}^*(892)^0\pi^0$, $\overline{K}^*(892)^0 \to K^-\pi^+$		(1.93 ± 0.24) %		711
$K_0^*(1430)^-\pi^+$, $K_0^{*-} \to K^-\pi^0$		$(4.7 \pm 2.2) \times 10^{-3}$		378
$\overline{K}_0^*(1430)^0\pi^0$, $\overline{K}_0^{*0} \to K^-\pi^+$		$(5.8 {}^{+5.0}_{-1.6}) \times 10^{-3}$		379
$K^*(1680)^-\pi^+$, $K^{*-} \to K^-\pi^0$		$(1.8 \pm 0.7) \times 10^{-3}$		46
$K^-\pi^+\pi^0$ nonresonant		$(1.14 {}^{+0.50}_{-0.20})$ %		844
$K_S^0 2\pi^0$		$(9.1 \pm 1.1) \times 10^{-3}$	S=2.2	843
$K_S^0(2\pi^0)_{S-wave}$		$(2.6 \pm 0.7) \times 10^{-3}$		–
$\overline{K}^*(892)^0\pi^0$, $\overline{K}^{*0} \to K_S^0\pi^0$		$(7.8 \pm 0.7) \times 10^{-3}$		711
$\overline{K}^*(1430)^0\pi^0$, $\overline{K}^{*0} \to K_S^0\pi^0$		$(4 \pm 23) \times 10^{-5}$		–
$\overline{K}^*(1680)^0\pi^0$, $\overline{K}^{*0} \to K_S^0\pi^0$		$(1.0 \pm 0.4) \times 10^{-3}$		–
$K_S^0 f_2(1270)$, $f_2 \to 2\pi^0$		$(2.3 \pm 1.1) \times 10^{-4}$		–
$2K_S^0$, one $K_S^0 \to 2\pi^0$		$(3.2 \pm 1.1) \times 10^{-4}$		–
$K^- 2\pi^+\pi^-$	[tt]	(8.11 ± 0.15) %	S=1.1	813
$K^-\pi^+\rho^0$ total		(6.77 ± 0.31) %		609
$K^-\pi^+\rho^0$ 3-body		$(6.0 \pm 1.6) \times 10^{-3}$		609
$\overline{K}^*(892)^0\rho^0$, $\overline{K}^{*0} \to K^-\pi^+$		$(10.0 \pm 0.5) \times 10^{-3}$		416
$(\overline{K}^*(892)^0\rho^0)_{S-wave}$, $\overline{K}^*(892)^0 \to K^-\pi^+$		$(5.8 \pm 0.8) \times 10^{-3}$		–
$(\overline{K}^*(892)^0\rho^0)_{P-wave}$, $\overline{K}^*(892)^0 \to K^-\pi^+$		$(1.86 \pm 0.18) \times 10^{-3}$		–
$(\overline{K}^*(892)^0\rho^0)_{D-wave}$, $\overline{K}^*(892)^0 \to K^-\pi^+$		$(6.6 \pm 0.7) \times 10^{-3}$		–
$\overline{K}^*(892)^0\rho^0$ transverse, $\overline{K}^{*0} \to K^-\pi^+$		(1.2 ± 0.4) %		417
$K^- a_1(1260)^+$, $a_1^+ \to \rho^0\pi^+$		(4.26 ± 0.32) %		327
$K^- a_1(1260)^+$, $a_1(1260)^+ \to (\rho^0\pi^+)_{S-wave}$		(4.3 ± 0.4) %		–
$K^- a_1(1260)^+$, $a_1(1260)^+ \to (\rho^0\pi^+)_{D-wave}$		$(2.4 \pm 1.1) \times 10^{-4}$		–
$K_1(1270)^-\pi^+$, $K_1^- \to K^-\pi^+\pi^-$ total		$(5.4 \pm 1.6) \times 10^{-3}$		–
$\overline{K}^*(892)^0\pi^+\pi^-$ 3-body, $\overline{K}^{*0} \to K^-\pi^+$		$(5.9 \pm 0.5) \times 10^{-3}$		685
$K_1(1270)^-\pi^+$, $K_1^- \to \overline{K}^*(892)^0\pi^-$, $\overline{K}^{*0} \to K^-\pi^+$		$(6.5 \pm 2.3) \times 10^{-4}$		484
$K_1(1270)^-\pi^+$, $K_1(1270)^- \to (\overline{K}^{*0}\pi^-)_{S-wave}$, $\overline{K}^*(892)^0 \to K^-\pi^+$		$(8 \pm 11) \times 10^{-5}$		–
$K_1(1270)^-\pi^+$, $K_1(1270)^- \to (\overline{K}^{*0}\pi^-)_{D-wave}$, $\overline{K}^*(892)^0 \to K^-\pi^+$		$(5.7 \pm 2.3) \times 10^{-4}$		–
$K_1(1270)^-\pi^+$, $K_1(1270)^- \to (K^-\rho^0)_{S-wave}$		$(2.8 \pm 0.5) \times 10^{-3}$		–
$K^- 2\pi^+\pi^-$ nonresonant		(1.78 ± 0.07) %		813

$K_S^0 \pi^+ \pi^- \pi^0$	[ggg]	$(5.1 \pm 0.6)\ \%$		813
$K_S^0 \eta,\ \eta \to \pi^+ \pi^- \pi^0$		$(1.10 \pm 0.07) \times 10^{-3}$		772
$K_S^0 \omega,\ \omega \to \pi^+ \pi^- \pi^0$		$(9.9 \pm 0.6) \times 10^{-3}$		670
$K^- 2\pi^+ \pi^- \pi^0$		$(4.2 \pm 0.4)\ \%$		771
$\overline{K}^*(892)^0 \pi^+ \pi^- \pi^0,\ \overline{K}^{*0} \to K^- \pi^+$		$(1.3 \pm 0.6)\ \%$		643
$K^- \pi^+ \omega,\ \omega \to \pi^+ \pi^- \pi^0$		$(2.7 \pm 0.5)\ \%$		605
$\overline{K}^*(892)^0 \omega,\ \overline{K}^{*0} \to K^- \pi^+,\ \omega \to \pi^+ \pi^- \pi^0$		$(6.5 \pm 3.0) \times 10^{-3}$		410
$K_S^0 \eta \pi^0$		$(5.5 \pm 1.1) \times 10^{-3}$		721
$K_S^0 a_0(980),\ a_0 \to \eta \pi^0$		$(6.5 \pm 2.0) \times 10^{-3}$		–
$\overline{K}^*(892)^0 \eta,\ \overline{K}^{*0} \to K_S^0 \pi^0$		$(1.6 \pm 0.5) \times 10^{-3}$		–
$K_S^0 2\pi^+ 2\pi^-$		$(2.61 \pm 0.29) \times 10^{-3}$		768
$K_S^0 \rho^0 \pi^+ \pi^-$, no $K^*(892)^-$		$(1.0 \pm 0.7) \times 10^{-3}$		–
$K^*(892)^- 2\pi^+ \pi^-,\ K^*(892)^- \to K_S^0 \pi^-$, no ρ^0		$(4 \pm 7) \times 10^{-4}$		642
$K^*(892)^- \rho^0 \pi^+,\ K^*(892)^- \to K_S^0 \pi^-$		$(1.6 \pm 0.6) \times 10^{-3}$		230
$K_S^0 2\pi^+ 2\pi^-$ nonresonant		$< 1.2 \times 10^{-3}$	CL=90%	768
$K^- 3\pi^+ 2\pi^-$		$(2.2 \pm 0.6) \times 10^{-4}$		713

Fractions of some of the following modes with resonances have already appeared above as submodes of particular charged-particle modes. These nine modes below are all corrected for unseen decays of the resonances.

$K_S^0 \eta$		$(4.80 \pm 0.30) \times 10^{-3}$		772
$K_S^0 \omega$		$(1.11 \pm 0.06)\ \%$		670
$K_S^0 \eta'(958)$		$(9.4 \pm 0.5) \times 10^{-3}$		565
$\overline{K}^*(892)^0 \pi^+ \pi^- \pi^0$		$(1.9 \pm 0.9)\ \%$		643
$K^- \pi^+ \omega$		$(3.0 \pm 0.6)\ \%$		605
$\overline{K}^*(892)^0 \omega$		$(1.1 \pm 0.5)\ \%$		410
$K^- \pi^+ \eta'(958)$		$(7.5 \pm 1.9) \times 10^{-3}$		479
$\overline{K}^*(892)^0 \eta'(958)$		$< 1.1 \times 10^{-3}$	CL=90%	119

Hadronic modes with three K's

$K_S^0 K^+ K^-$		$(4.35 \pm 0.32) \times 10^{-3}$		544
$K_S^0 a_0(980)^0,\ a_0^0 \to K^+ K^-$		$(2.9 \pm 0.4) \times 10^{-3}$		–
$K^- a_0(980)^+,\ a_0^+ \to K^+ K_S^0$		$(5.8 \pm 1.7) \times 10^{-4}$		–
$K^+ a_0(980)^-,\ a_0^- \to K^- K_S^0$		$< 1.1 \times 10^{-4}$	CL=95%	–
$K_S^0 f_0(980),\ f_0 \to K^+ K^-$		$< 9 \times 10^{-5}$	CL=95%	–
$K_S^0 \phi,\ \phi \to K^+ K^-$		$(2.00 \pm 0.15) \times 10^{-3}$		520
$K_S^0 f_0(1370),\ f_0 \to K^+ K^-$		$(1.7 \pm 1.1) \times 10^{-4}$		–
$3K_S^0$		$(7.5 \pm 0.6) \times 10^{-4}$	S=1.3	539
$K^+ 2K^- \pi^+$		$(2.22 \pm 0.31) \times 10^{-4}$		434
$K^+ K^- \overline{K}^*(892)^0,\ \overline{K}^{*0} \to K^- \pi^+$		$(4.4 \pm 1.7) \times 10^{-5}$		†
$K^- \pi^+ \phi,\ \phi \to K^+ K^-$		$(4.0 \pm 1.7) \times 10^{-5}$		422
$\phi \overline{K}^*(892)^0,\ \phi \to K^+ K^-,\ \overline{K}^{*0} \to K^- \pi^+$		$(1.06 \pm 0.20) \times 10^{-4}$		†
$K^+ 2K^- \pi^+$ nonresonant		$(3.3 \pm 1.5) \times 10^{-5}$		434
$2K_S^0 K^\pm \pi^\mp$		$(5.8 \pm 1.2) \times 10^{-4}$		427

Pionic modes

$\pi^+\pi^-$	$(1.407\pm0.025)\times10^{-3}$	S=1.1	922
$2\pi^0$	$(8.22\pm0.25)\times10^{-4}$		923
$\pi^+\pi^-\pi^0$	(1.47 ± 0.06) %	S=2.1	907
$\rho^+\pi^-$	$(10.0\pm0.4)\times10^{-3}$		764
$\rho^0\pi^0$	$(3.81\pm0.23)\times10^{-3}$		764
$\rho^-\pi^+$	$(5.08\pm0.25)\times10^{-3}$		764
$\rho(1450)^+\pi^-$, $\rho^+\to\pi^+\pi^0$	$(1.6\pm2.0)\times10^{-5}$		–
$\rho(1450)^0\pi^0$, $\rho^0\to\pi^+\pi^-$	$(4.4\pm1.9)\times10^{-5}$		–
$\rho(1450)^-\pi^+$, $\rho^-\to\pi^-\pi^0$	$(2.6\pm0.4)\times10^{-4}$		–
$\rho(1700)^+\pi^-$, $\rho^+\to\pi^+\pi^0$	$(6.0\pm1.5)\times10^{-4}$		–
$\rho(1700)^0\pi^0$, $\rho^0\to\pi^+\pi^-$	$(7.3\pm1.7)\times10^{-4}$		–
$\rho(1700)^-\pi^+$, $\rho^-\to\pi^-\pi^0$	$(4.7\pm1.1)\times10^{-4}$		–
$f_0(980)\pi^0$, $f_0\to\pi^+\pi^-$	$(3.7\pm0.8)\times10^{-5}$		–
$f_0(500)\pi^0$, $f_0\to\pi^+\pi^-$	$(1.20\pm0.21)\times10^{-4}$		–
$f_0(1370)\pi^0$, $f_0\to\pi^+\pi^-$	$(5.4\pm2.1)\times10^{-5}$		–
$f_0(1500)\pi^0$, $f_0\to\pi^+\pi^-$	$(5.7\pm1.6)\times10^{-5}$		–
$f_0(1710)\pi^0$, $f_0\to\pi^+\pi^-$	$(4.5\pm1.6)\times10^{-5}$		–
$f_2(1270)\pi^0$, $f_2\to\pi^+\pi^-$	$(1.94\pm0.21)\times10^{-4}$		–
$\pi^+\pi^-\pi^0$ nonresonant	$(1.2\pm0.4)\times10^{-4}$		907
$3\pi^0$	$<3.5\times10^{-4}$	CL=90%	908
$2\pi^+2\pi^-$	$(7.45\pm0.20)\times10^{-3}$		880
$a_1(1260)^+\pi^-$, $a_1^+\to 2\pi^+\pi^-$ total	$(4.47\pm0.31)\times10^{-3}$		–
$a_1(1260)^+\pi^-$, $a_1^+\to\rho^0\pi^+$ S-wave	$(3.09\pm0.21)\times10^{-3}$		–
$a_1(1260)^+\pi^-$, $a_1^+\to\rho^0\pi^+$ D-wave	$(1.9\pm0.5)\times10^{-4}$		–
$a_1(1260)^+\pi^-$, $a_1^+\to\sigma\pi^+$	$(6.3\pm0.7)\times10^{-4}$		–
$a_1(1260)^-\pi^+$, $a_1^-\to\rho^0\pi^-$ S-wave	$(2.3\pm0.9)\times10^{-4}$		–
$a_1(1260)^-\pi^+$, $a_1^-\to\sigma\pi^-$	$(6.0\pm3.3)\times10^{-5}$		–
$\pi(1300)^+\pi^-$, $\pi(1300)^+\to\sigma\pi^+$	$(5.1\pm2.6)\times10^{-4}$		–
$\pi(1300)^-\pi^+$, $\pi(1300)^-\to\sigma\pi^-$	$(2.2\pm2.1)\times10^{-4}$		–
$a_1(1640)^+\pi^-$, $a_1^+\to\rho^0\pi^+$ D-wave	$(3.1\pm1.6)\times10^{-4}$		–
$a_1(1640)^+\pi^-$, $a_1^+\to\sigma\pi^+$	$(1.8\pm1.4)\times10^{-4}$		–
$\pi_2(1670)^+\pi^-$, $\pi_2^+\to f_2(1270)^0\pi^+$, $f_2^0\to\pi^+\pi^-$	$(2.0\pm0.9)\times10^{-4}$		–
$\pi_2(1670)^+\pi^-$, $\pi_2^+\to\sigma\pi^+$	$(2.6\pm1.0)\times10^{-4}$		–
$2\rho^0$ total	$(1.83\pm0.13)\times10^{-3}$		518
$2\rho^0$, parallel helicities	$(8.2\pm3.2)\times10^{-5}$		–
$2\rho^0$, perpendicular helicities	$(4.8\pm0.6)\times10^{-4}$		–
$2\rho^0$, longitudinal helicities	$(1.25\pm0.10)\times10^{-3}$		–
$2\rho(770)^0$, S-wave	$(1.8\pm1.2)\times10^{-4}$		–
$2\rho(770)^0$, P-wave	$(5.2\pm1.3)\times10^{-4}$		–
$2\rho(770)^0$, D-wave	$(6.1\pm3.0)\times10^{-4}$		–
Resonant $(\pi^+\pi^-)\pi^+\pi^-$ 3-body total	$(1.49\pm0.12)\times10^{-3}$		–
$\sigma\pi^+\pi^-$	$(6.1\pm0.9)\times10^{-4}$		–
$\sigma\rho(770)^0$	$(4.9\pm2.5)\times10^{-4}$		–

$f_0(980)\pi^+\pi^-$, $f_0 \to \pi^+\pi^-$		$(1.8 \pm 0.5) \times 10^{-4}$		–
$f_2(1270)\pi^+\pi^-$, $f_2 \to \pi^+\pi^-$		$(3.7 \pm 0.6) \times 10^{-4}$		–
$2f_2(1270)$, $f_2 \to \pi^+\pi^-$		$(1.6 \pm 1.8) \times 10^{-4}$		–
$f_0(1370)\sigma$, $f_0 \to \pi^+\pi^-$		$(1.6 \pm 0.5) \times 10^{-3}$		–
$\pi^+\pi^- 2\pi^0$		(1.00 ± 0.09) %		882
$\eta\pi^0$	[hhh]	$(6.7 \pm 0.6) \times 10^{-4}$		846
$\omega\pi^0$	[hhh]	$(1.17 \pm 0.35) \times 10^{-4}$		761
$2\pi^+ 2\pi^- \pi^0$		$(4.2 \pm 0.5) \times 10^{-3}$		844
$\eta\pi^+\pi^-$	[hhh]	$(1.09 \pm 0.16) \times 10^{-3}$		827
$\omega\pi^+\pi^-$	[hhh]	$(1.6 \pm 0.5) \times 10^{-3}$		738
$3\pi^+ 3\pi^-$		$(4.2 \pm 1.2) \times 10^{-4}$		795
$\eta'(958)\pi^0$		$(9.0 \pm 1.4) \times 10^{-4}$		678
$\eta'(958)\pi^+\pi^-$		$(4.5 \pm 1.7) \times 10^{-4}$		650
2η		$(1.68 \pm 0.20) \times 10^{-3}$		754
$\eta\eta'(958)$		$(1.05 \pm 0.26) \times 10^{-3}$		537

Hadronic modes with a $K\overline{K}$ pair

$K^+ K^-$		$(3.97 \pm 0.07) \times 10^{-3}$	S=1.4	791
$2K^0_S$		$(1.70 \pm 0.12) \times 10^{-4}$		789
$K^0_S K^- \pi^+$		$(3.3 \pm 0.5) \times 10^{-3}$	S=1.1	739
$\overline{K}^*(892)^0 K^0_S$, $\overline{K}^{*0} \to K^-\pi^+$		$(8.1 \pm 1.6) \times 10^{-5}$		608
$K^*(892)^+ K^-$, $K^{*+} \to K^0_S \pi^+$		$(1.86 \pm 0.30) \times 10^{-3}$		–
$\overline{K}^*(1410)^0 K^0_S$, $\overline{K}^{*0} \to K^-\pi^+$		$(1.2 \pm 1.8) \times 10^{-4}$		–
$K^*(1410)^+ K^-$, $K^{*+} \to K^0_S \pi^+$		$(3.1 \pm 1.9) \times 10^{-4}$		–
$(K^-\pi^+)_{S-wave} K^0_S$		$(5.9 \pm 2.8) \times 10^{-4}$		739
$(K^0_S\pi^+)_{S-wave} K^-$		$(3.8 \pm 1.0) \times 10^{-4}$		739
$a_0(980)^-\pi^+$, $a_0^- \to K^0_S K^-$		$(1.3 \pm 1.4) \times 10^{-4}$		–
$a_0(1450)^-\pi^+$, $a_0^- \to K^0_S K^-$		$(2.4 \pm 2.0) \times 10^{-5}$		–
$a_2(1320)^-\pi^+$, $a_2^- \to K^0_S K^-$		$(5 \pm 5) \times 10^{-6}$		–
$\rho(1450)^-\pi^+$, $\rho^- \to K^0_S K^-$		$(4.6 \pm 2.5) \times 10^{-5}$		–
$K^0_S K^+ \pi^-$		$(2.13 \pm 0.34) \times 10^{-3}$	S=1.1	739
$K^*(892)^0 K^0_S$, $K^{*0} \to K^+\pi^-$		$(1.10 \pm 0.21) \times 10^{-4}$		608
$K^*(892)^- K^+$, $K^{*-} \to K^0_S \pi^-$		$(6.1 \pm 1.0) \times 10^{-4}$		–
$K^*(1410)^0 K^0_S$, $K^{*0} \to K^+\pi^+$		$(5 \pm 8) \times 10^{-5}$		–
$K^*(1410)^- K^+$, $K^{*-} \to K^0_S \pi^-$		$(2.5 \pm 2.0) \times 10^{-4}$		–
$(K^+\pi^-)_{S-wave} K^0_S$		$(3.6 \pm 1.9) \times 10^{-4}$		739
$(K^0_S\pi^-)_{S-wave} K^+$		$(1.3 \pm 0.6) \times 10^{-4}$		739
$a_0(980)^+\pi^-$, $a_0^+ \to K^0_S K^+$		$(6 \pm 4) \times 10^{-4}$		–
$a_0(1450)^+\pi^-$, $a_0^+ \to K^0_S K^+$		$(3.2 \pm 2.5) \times 10^{-5}$		–
$\rho(1700)^+\pi^-$, $\rho^+ \to K^0_S K^+$		$(1.1 \pm 0.6) \times 10^{-5}$		–
$K^+ K^- \pi^0$		$(3.37 \pm 0.15) \times 10^{-3}$		743
$K^*(892)^+ K^-$, $K^*(892)^+ \to K^+\pi^0$		$(1.50 \pm 0.07) \times 10^{-3}$		–
$K^*(892)^- K^+$, $K^*(892)^- \to K^-\pi^0$		$(5.4 \pm 0.4) \times 10^{-4}$		–
$(K^+\pi^0)_{S-wave} K^-$		$(2.40 \pm 0.17) \times 10^{-3}$		743
$(K^-\pi^0)_{S-wave} K^+$		$(1.3 \pm 0.5) \times 10^{-4}$		743

$f_0(980)\pi^0$, $f_0 \to K^+K^-$		$(3.5 \pm 0.6) \times 10^{-4}$		–
$\phi\pi^0$, $\phi \to K^+K^-$		$(6.5 \pm 0.4) \times 10^{-4}$		–
$2K^0_S\pi^0$		$< 5.9 \times 10^{-4}$		740
$K^+K^-\pi^+\pi^-$		$(2.44 \pm 0.11) \times 10^{-3}$		677
$\phi(\pi^+\pi^-)_{S-wave}$, $\phi \to K^+K^-$		$(10 \pm 5) \times 10^{-5}$		614
$(\phi\rho^0)_{S-wave}$, $\phi \to K^+K^-$		$(6.8 \pm 0.6) \times 10^{-4}$		250
$(\phi\rho^0)_{P-wave}$, $\phi \to K^+K^-$		$(3.9 \pm 1.9) \times 10^{-5}$		–
$(\phi\rho^0)_{D-wave}$, $\phi \to K^+K^-$		$(4.1 \pm 1.4) \times 10^{-5}$		–
$(K^*(892)^0\overline{K}^*(892)^0)_{S-wave}$, $K^{*0} \to K^\pm\pi^\mp$		$(1.1 \pm 0.5) \times 10^{-4}$		–
$(K^*(892)^0\overline{K}^*(892)^0)_{P-wave}$, $K^* \to K^\pm\pi^\mp$		$(9 \pm 4) \times 10^{-5}$		–
$(K^*(892)^0\overline{K}^*(892)^0)_{D-wave}$, $K^* \to K^\pm\pi^\mp$		$(9.7 \pm 2.3) \times 10^{-5}$		–
$K^*(892)^0(K^-\pi^+)_{S-wave}$ 3-body, $K^{*0} \to K^+\pi^-$		$(1.4 \pm 0.6) \times 10^{-4}$		–
$K_1(1270)^+K^-$, $K_1^+ \to K^{*0}\pi^+$		$(1.3 \pm 0.9) \times 10^{-4}$		–
$K_1(1270)^+K^-$, $K_1^+ \to K^*(1430)^0\pi^+$, $K^{*0} \to K^+\pi^-$		$(1.5 \pm 0.5) \times 10^{-4}$		–
$K_1(1270)^+K^-$, $K_1^+ \to \rho^0K^+$		$(2.2 \pm 0.6) \times 10^{-4}$		–
$K_1(1270)^+K^-$, $K_1^+ \to \omega(782)K^+$, $\omega \to \pi^+\pi^-$		$(1.5 \pm 1.2) \times 10^{-5}$		–
$K_1(1270)^-K^+$, $K_1^- \to \rho^0K^-$		$(1.3 \pm 0.4) \times 10^{-4}$		–
$K_1(1400)^+K^-$, $K_1^+ \to K^*(892)^0\pi^+$, $K^{*0} \to K^+\pi^-$		$(3.0 \pm 1.7) \times 10^{-4}$		–
$K_1(1680)^+K^-$, $K_1^+ \to K^{*0}\pi^+$, $K^{*0} \to K^+\pi^-$		$(8.8 \pm 3.1) \times 10^{-5}$		–
$K^+K^-\pi^+\pi^-$ non-resonant		$(2.7 \pm 0.6) \times 10^{-4}$		–
$2K^0_S\pi^+\pi^-$		$(1.20 \pm 0.23) \times 10^{-3}$		673
$K^0_SK^-2\pi^+\pi^-$		$< 1.4 \times 10^{-4}$	CL=90%	595
$K^+K^-\pi^+\pi^-\pi^0$		$(3.1 \pm 2.0) \times 10^{-3}$		600

Other $K\overline{K}X$ modes. They include all decay modes of the ϕ, η, and ω.

$\phi\eta$		$(1.4 \pm 0.5) \times 10^{-4}$		489
$\phi\omega$		$< 2.1 \times 10^{-3}$	CL=90%	238

Radiative modes

$\rho^0\gamma$		$(1.76 \pm 0.31) \times 10^{-5}$		771
$\omega\gamma$		$< 2.4 \times 10^{-4}$	CL=90%	768
$\phi\gamma$		$(2.74 \pm 0.19) \times 10^{-5}$		654
$\overline{K}^*(892)^0\gamma$		$(4.1 \pm 0.7) \times 10^{-4}$		719

Doubly Cabibbo suppressed (*DC*) modes or $\Delta C = 2$ forbidden via mixing (*C2M*) modes

$K^+\ell^-\overline{\nu}_\ell$ via $\overline{D}^0$		$< 2.2 \times 10^{-5}$	CL=90%	–
K^+ or $K^*(892)^+e^-\overline{\nu}_e$ via $\overline{D}^0$		$< 6 \times 10^{-5}$	CL=90%	–
$K^+\pi^-$	*DC*	$(1.48 \pm 0.07) \times 10^{-4}$	S=2.8	861
$K^+\pi^-$ via DCS		$(1.366 \pm 0.028) \times 10^{-4}$		–
$K^+\pi^-$ via $\overline{D}^0$		$< 1.6 \times 10^{-5}$	CL=95%	861
$K^0_S\pi^+\pi^-$ in $D^0 \to \overline{D}^0$		$< 1.7 \times 10^{-4}$	CL=95%	–

$K^*(892)^+\pi^-$, $K^{*+} \to K^0_S\pi^+$	DC		$(1.11\ {}^{+\ 0.60}_{-\ 0.33}) \times 10^{-4}$		711
$K^*_0(1430)^+\pi^-$, $K^{*+}_0 \to K^0_S\pi^+$	DC		$< 1.4 \times 10^{-5}$		–
$K^*_2(1430)^+\pi^-$, $K^{*+}_2 \to K^0_S\pi^+$	DC		$< 3.3 \times 10^{-5}$		–
$K^+\pi^-\pi^0$	DC		$(3.01 \pm 0.15) \times 10^{-4}$		844
$K^+\pi^-\pi^0$ via $\overline{D}^0$			$(7.5 \pm 0.5) \times 10^{-4}$		–
$K^+\pi^+2\pi^-$ via DCS			$(2.45 \pm 0.07) \times 10^{-4}$		–
$K^+\pi^+2\pi^-$	DC		$(2.61 \pm 0.06) \times 10^{-4}$		813
$K^+\pi^+2\pi^-$ via $\overline{D}^0$			$(7.8 \pm 2.9) \times 10^{-6}$		812
μ^- anything via $\overline{D}^0$			$< 4 \times 10^{-4}$	CL=90%	–

$\Delta C = 1$ weak neutral current (*C1*) modes, Lepton Family number (*LF*) violating modes, Lepton (*L*) or Baryon (*B*) number violating modes

$\gamma\gamma$	C1		$< 8.5 \times 10^{-7}$	CL=90%	932
e^+e^-	C1		$< 7.9 \times 10^{-8}$	CL=90%	932
$\mu^+\mu^-$	C1		$< 6.2 \times 10^{-9}$	CL=90%	926
$\pi^0 e^+e^-$	C1		$< 4.5 \times 10^{-5}$	CL=90%	928
$\pi^0\mu^+\mu^-$	C1		$< 1.8 \times 10^{-4}$	CL=90%	915
ηe^+e^-	C1		$< 1.1 \times 10^{-4}$	CL=90%	852
$\eta\mu^+\mu^-$	C1		$< 5.3 \times 10^{-4}$	CL=90%	838
$\pi^+\pi^-e^+e^-$	C1		$< 3.73 \times 10^{-4}$	CL=90%	922
$\rho^0 e^+e^-$	C1		$< 1.0 \times 10^{-4}$	CL=90%	771
$\pi^+\pi^-\mu^+\mu^-$	C1		$(9.6 \pm 1.2) \times 10^{-7}$		894
$\pi^+\pi^-\mu^+\mu^-$ (non-res)			$< 5.5 \times 10^{-7}$	CL=90%	–
$\rho^0\mu^+\mu^-$	C1		$< 2.2 \times 10^{-5}$	CL=90%	754
ωe^+e^-	C1		$< 1.8 \times 10^{-4}$	CL=90%	768
$\omega\mu^+\mu^-$	C1		$< 8.3 \times 10^{-4}$	CL=90%	751
$K^-K^+e^+e^-$	C1		$< 3.15 \times 10^{-4}$	CL=90%	791
ϕe^+e^-	C1		$< 5.2 \times 10^{-5}$	CL=90%	654
$K^-K^+\mu^+\mu^-$	C1		$(1.54 \pm 0.32) \times 10^{-7}$		710
$K^-K^+\mu^+\mu^-$ (non-res)			$< 3.3 \times 10^{-5}$	CL=90%	–
$\phi\mu^+\mu^-$	C1		$< 3.1 \times 10^{-5}$	CL=90%	631
$\overline{K}^0 e^+e^-$		[zz]	$< 1.1 \times 10^{-4}$	CL=90%	866
$\overline{K}^0\mu^+\mu^-$		[zz]	$< 2.6 \times 10^{-4}$	CL=90%	852
$K^-\pi^+e^+e^-$	C1		$< 3.85 \times 10^{-4}$	CL=90%	861
$\overline{K}^*(892)^0 e^+e^-$		[zz]	$< 4.7 \times 10^{-5}$	CL=90%	719
$K^-\pi^+\mu^+\mu^-$	C1		$< 3.59 \times 10^{-4}$	CL=90%	829
$K^-\pi^+\mu^+\mu^-$, $675 < m_{\mu\mu} < 875$ MeV			$(4.2 \pm 0.4) \times 10^{-6}$		–
$\overline{K}^*(892)^0\mu^+\mu^-$		[zz]	$< 2.4 \times 10^{-5}$	CL=90%	700
$\pi^+\pi^-\pi^0\mu^+\mu^-$	C1		$< 8.1 \times 10^{-4}$	CL=90%	863
$\mu^\pm e^\mp$	LF	[hh]	$< 1.3 \times 10^{-8}$	CL=90%	929
$\pi^0 e^\pm\mu^\mp$	LF	[hh]	$< 8.6 \times 10^{-5}$	CL=90%	924
$\eta e^\pm\mu^\mp$	LF	[hh]	$< 1.0 \times 10^{-4}$	CL=90%	848
$\pi^+\pi^-e^\pm\mu^\mp$	LF	[hh]	$< 1.5 \times 10^{-5}$	CL=90%	911
$\rho^0 e^\pm\mu^\mp$	LF	[hh]	$< 4.9 \times 10^{-5}$	CL=90%	767
$\omega e^\pm\mu^\mp$	LF	[hh]	$< 1.2 \times 10^{-4}$	CL=90%	764
$K^-K^+e^\pm\mu^\mp$	LF	[hh]	$< 1.8 \times 10^{-4}$	CL=90%	754
$\phi e^\pm\mu^\mp$	LF	[hh]	$< 3.4 \times 10^{-5}$	CL=90%	648
$\overline{K}^0 e^\pm\mu^\mp$	LF	[hh]	$< 1.0 \times 10^{-4}$	CL=90%	863
$K^-\pi^+e^\pm\mu^\mp$	LF	[hh]	$< 5.53 \times 10^{-4}$	CL=90%	848

$\overline{K}^*(892)^0 e^\pm \mu^\mp$	LF	[hh]	< 8.3	$\times 10^{-5}$	CL=90%	714
$2\pi^- 2e^+ +$ c.c.	L		< 1.12	$\times 10^{-4}$	CL=90%	922
$2\pi^- 2\mu^+ +$ c.c.	L		< 2.9	$\times 10^{-5}$	CL=90%	894
$K^- \pi^- 2e^+ +$ c.c.	L		< 2.06	$\times 10^{-4}$	CL=90%	861
$K^- \pi^- 2\mu^+ +$ c.c.	L		< 3.9	$\times 10^{-4}$	CL=90%	829
$2K^- 2e^+ +$ c.c.	L		< 1.52	$\times 10^{-4}$	CL=90%	791
$2K^- 2\mu^+ +$ c.c.	L		< 9.4	$\times 10^{-5}$	CL=90%	710
$\pi^- \pi^- e^+ \mu^+ +$ c.c.	L		< 7.9	$\times 10^{-5}$	CL=90%	911
$K^- \pi^- e^+ \mu^+ +$ c.c.	L		< 2.18	$\times 10^{-4}$	CL=90%	848
$2K^- e^+ \mu^+ +$ c.c.	L		< 5.7	$\times 10^{-5}$	CL=90%	754
$p e^-$	L,B	[iii]	< 1.0	$\times 10^{-5}$	CL=90%	696
$\overline{p} e^+$	L,B	[jjj]	< 1.1	$\times 10^{-5}$	CL=90%	696

$D^*(2007)^0$

$I(J^P) = \frac{1}{2}(1^-)$
I, J, P need confirmation.

Mass $m = 2006.85 \pm 0.05$ MeV (S = 1.1)
$m_{D^{*0}} - m_{D^0} = 142.016 \pm 0.030$ MeV (S = 1.5)
Full width $\Gamma < 2.1$ MeV, CL = 90%

$\overline{D}^*(2007)^0$ modes are charge conjugates of modes below.

$D^*(2007)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^0 \pi^0$	(64.7 ± 0.9) %	43
$D^0 \gamma$	(35.3 ± 0.9) %	137

$D^*(2010)^\pm$

$I(J^P) = \frac{1}{2}(1^-)$
I, J, P need confirmation.

Mass $m = 2010.26 \pm 0.05$ MeV
$m_{D^*(2010)^+} - m_{D^+} = 140.603 \pm 0.015$ MeV
$m_{D^*(2010)^+} - m_{D^0} = 145.4257 \pm 0.0017$ MeV
Full width $\Gamma = 83.4 \pm 1.8$ keV

$D^*(2010)^-$ modes are charge conjugates of the modes below.

$D^*(2010)^\pm$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D^0 \pi^+$	(67.7 ± 0.5) %	39
$D^+ \pi^0$	(30.7 ± 0.5) %	38
$D^+ \gamma$	(1.6 ± 0.4) %	136

$D_0^*(2400)^0$

$I(J^P) = \frac{1}{2}(0^+)$

Mass $m = 2318 \pm 29$ MeV (S = 1.7)
Full width $\Gamma = 267 \pm 40$ MeV

$D_1(2420)^0$

$I(J^P) = \frac{1}{2}(1^+)$
I needs confirmation.

Mass $m = 2420.8 \pm 0.5$ MeV (S = 1.3)
$m_{D_1^0} - m_{D^{*+}} = 410.6 \pm 0.5$ (S = 1.3)
Full width $\Gamma = 31.7 \pm 2.5$ MeV (S = 3.5)

$D_2^*(2460)^0$

$I(J^P) = \frac{1}{2}(2^+)$

$J^P = 2^+$ assignment strongly favored.

Mass $m = 2460.7 \pm 0.4$ MeV (S = 3.1)
$m_{D_2^{*0}} - m_{D^+} = 591.0 \pm 0.4$ MeV (S = 2.9)
$m_{D_2^{*0}} - m_{D^{*+}} = 450.4 \pm 0.4$ MeV (S = 2.9)
Full width $\Gamma = 47.5 \pm 1.1$ MeV (S = 1.8)

$D_2^*(2460)^\pm$

$I(J^P) = \frac{1}{2}(2^+)$

$J^P = 2^+$ assignment strongly favored.

Mass $m = 2465.4 \pm 1.3$ MeV (S = 3.1)
$m_{D_2^*(2460)^\pm} - m_{D_2^*(2460)^0} = 2.4 \pm 1.7$ MeV
Full width $\Gamma = 46.7 \pm 1.2$ MeV

CHARMED, STRANGE MESONS ($C = S = \pm 1$)

$D_s^+ = c\overline{s}$, $D_s^- = \overline{c}s$, similarly for D_s^*'s

$D_s^\pm$

$I(J^P) = 0(0^-)$

Mass $m = 1968.34 \pm 0.07$ MeV
$m_{D_s^\pm} - m_{D^\pm} = 98.69 \pm 0.05$ MeV
Mean life $\tau = (504 \pm 4) \times 10^{-15}$ s (S = 1.2)
$c\tau = 151.2$ μm

CP-violating decay-rate asymmetries

$A_{CP}(\mu^\pm \nu) = (5 \pm 6)\%$
$A_{CP}(K^\pm K_S^0) = (0.08 \pm 0.26)\%$
$A_{CP}(K^+ K^- \pi^\pm) = (-0.5 \pm 0.9)\%$
$A_{CP}(\phi \pi^\pm) = (-0.38 \pm 0.27)\%$
$A_{CP}(K^\pm K_S^0 \pi^0) = (-2 \pm 6)\%$
$A_{CP}(2K_S^0 \pi^\pm) = (3 \pm 5)\%$
$A_{CP}(K^+ K^- \pi^\pm \pi^0) = (0.0 \pm 3.0)\%$
$A_{CP}(K^\pm K_S^0 \pi^+ \pi^-) = (-6 \pm 5)\%$
$A_{CP}(K_S^0 K^\mp 2\pi^\pm) = (4.1 \pm 2.8)\%$
$A_{CP}(\pi^+ \pi^- \pi^\pm) = (-0.7 \pm 3.1)\%$
$A_{CP}(\pi^\pm \eta) = (1.1 \pm 3.1)\%$
$A_{CP}(\pi^\pm \eta') = (-0.9 \pm 0.5)\%$
$A_{CP}(\eta \pi^\pm \pi^0) = (-1 \pm 4)\%$
$A_{CP}(\eta' \pi^\pm \pi^0) = (0 \pm 8)\%$
$A_{CP}(K^\pm \pi^0) = (-27 \pm 24)\%$
$A_{CP}(\overline{K}^0 / K^0 \pi^\pm) = (0.4 \pm 0.5)\%$
$A_{CP}(K_S^0 \pi^\pm) = (3.1 \pm 2.6)\%$ (S = 1.7)
$A_{CP}(K^\pm \pi^+ \pi^-) = (4 \pm 5)\%$
$A_{CP}(K^\pm \eta) = (9 \pm 15)\%$
$A_{CP}(K^\pm \eta'(958)) = (6 \pm 19)\%$

***CP* violating asymmetries of *P*-odd (*T*-odd) moments**

$A_T(K^0_S K^{\pm}\pi^+\pi^-) = (-14 \pm 8) \times 10^{-3}$ [ss]

$D_s^+ \rightarrow \phi \ell^+ \nu_\ell$ form factors

$r_2 = 0.84 \pm 0.11$ (S = 2.4)
$r_v = 1.80 \pm 0.08$
$\Gamma_L/\Gamma_T = 0.72 \pm 0.18$

Unless otherwise noted, the branching fractions for modes with a resonance in the final state include all the decay modes of the resonance. D_s^- modes are charge conjugates of the modes below.

D_s^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Inclusive modes				
e^+ semileptonic	[kkk]	(6.5 ±0.4) %		–
π^+ anything		(119.3 ±1.4) %		–
π^- anything		(43.2 ±0.9) %		–
π^0 anything		(123 ±7) %		–
K^- anything		(18.7 ±0.5) %		–
K^+ anything		(28.9 ±0.7) %		–
K^0_S anything		(19.0 ±1.1) %		–
η anything	[lll]	(29.9 ±2.8) %		–
ω anything		(6.1 ±1.4) %		–
η' anything	[nnn]	(10.3 ±1.4) %	S=1.1	–
$f_0(980)$ anything, $f_0 \rightarrow \pi^+\pi^-$		< 1.3 %	CL=90%	–
ϕ anything		(15.7 ±1.0) %		–
K^+K^- anything		(15.8 ±0.7) %		–
$K^0_S K^+$ anything		(5.8 ±0.5) %		–
$K^0_S K^-$ anything		(1.9 ±0.4) %		–
$2K^0_S$ anything		(1.70±0.32) %		–
$2K^+$ anything		< 2.6 $\times 10^{-3}$	CL=90%	–
$2K^-$ anything		< 6 $\times 10^{-4}$	CL=90%	–
Leptonic and semileptonic modes				
$e^+\nu_e$		< 8.3 $\times 10^{-5}$	CL=90%	984
$\mu^+\nu_\mu$		(5.50±0.23) $\times 10^{-3}$		981
$\tau^+\nu_\tau$		(5.48±0.23) %		182
$K^+K^-e^+\nu_e$		—		851
$\phi e^+\nu_e$	[ooo]	(2.39±0.16) %	S=1.3	720
$\phi \mu^+\nu_\mu$		(1.9 ±0.5) %		715
$\eta e^+\nu_e + \eta'(958) e^+\nu_e$	[ooo]	(3.03±0.24) %		–
$\eta e^+\nu_e$	[ooo]	(2.29±0.19) %		908
$\eta'(958) e^+\nu_e$	[ooo]	(7.4 ±1.4) $\times 10^{-3}$		751
$\eta \mu^+\nu_\mu$		(2.4 ±0.5) %		905
$\eta'(958) \mu^+\nu_\mu$		(1.1 ±0.5) %		747
$\omega e^+\nu_e$	[ppp]	< 2.0 $\times 10^{-3}$	CL=90%	829
$K^0 e^+\nu_e$		(3.9 ±0.9) $\times 10^{-3}$		921
$K^*(892)^0 e^+\nu_e$	[ooo]	(1.8 ±0.4) $\times 10^{-3}$		782
Hadronic modes with a $K\overline{K}$ pair				
$K^+K^0_S$		(1.50±0.05) %		850
$K^+\overline{K}^0$		(2.95±0.14) %		850
$K^+K^-\pi^+$	[tt]	(5.45±0.17) %	S=1.2	805
$\phi\pi^+$	[ooo,qqq]	(4.5 ±0.4) %		712

$\phi\pi^+$, $\phi \to K^+K^-$	[qqq]	(2.27 ± 0.08) %		712
$K^+\overline{K}^*(892)^0$, $\overline{K}^{*0} \to K^-\pi^+$		(2.61 ± 0.09) %		416
$f_0(980)\pi^+$, $f_0 \to K^+K^-$		(1.15 ± 0.32) %		732
$f_0(1370)\pi^+$, $f_0 \to K^+K^-$		$(7\ \pm5\ )\times10^{-4}$		–
$f_0(1710)\pi^+$, $f_0 \to K^+K^-$		$(6.7\pm2.9)\times10^{-4}$		198
$K^+\overline{K}^*_0(1430)^0$, $\overline{K}^*_0 \to K^-\pi^+$		$(1.9\pm0.4)\times10^{-3}$		218
$K^+K^0_S\pi^0$		(1.52 ± 0.22) %		805
$2K^0_S\pi^+$		$(7.7\pm0.6)\times10^{-3}$		802
$K^0\overline{K}^0\pi^+$		—		802
$K^*(892)^+\overline{K}^0$	[ooo]	(5.4 ± 1.2) %		683
$K^+K^-\pi^+\pi^0$		(6.3 ± 0.6) %		748
$\phi\rho^+$	[ooo]	$(8.4\ ^{+1.9}_{-2.3})$ %		401
$K^0_S K^-2\pi^+$		(1.68 ± 0.10) %		744
$K^*(892)^+\overline{K}^*(892)^0$	[ooo]	(7.2 ± 2.6) %		416
$K^+K^0_S\pi^+\pi^-$		(1.00 ± 0.08) %		744
$K^+K^-2\pi^+\pi^-$		$(8.7\pm1.5)\times10^{-3}$		673
$\phi 2\pi^+\pi^-$	[ooo]	(1.21 ± 0.16) %		640
$K^+K^-\rho^0\pi^+$ non-ϕ		$< 2.6\times10^{-4}$	CL=90%	249
$\phi\rho^0\pi^+$, $\phi \to K^+K^-$		$(6.5\pm1.3)\times10^{-3}$		181
$\phi a_1(1260)^+$, $\phi \to K^+K^-$, $a_1^+ \to \rho^0\pi^+$		$(7.5\pm1.2)\times10^{-3}$		†
$K^+K^-2\pi^+\pi^-$ nonresonant		$(9\ \pm7\ )\times10^{-4}$		673
$2K^0_S 2\pi^+\pi^-$		$(9\ \pm4\ )\times10^{-4}$		669
Hadronic modes without K's				
$\pi^+\pi^0$		$< 3.5\times10^{-4}$	CL=90%	975
$2\pi^+\pi^-$		(1.09 ± 0.05) %	S=1.1	959
$\rho^0\pi^+$		$(2.0\pm1.2)\times10^{-4}$		825
$\pi^+(\pi^+\pi^-)_{S-\text{wave}}$	[rrr]	$(9.1\pm0.4)\times10^{-3}$		959
$f_2(1270)\pi^+$, $f_2 \to \pi^+\pi^-$		$(1.10\pm0.20)\times10^{-3}$		559
$\rho(1450)^0\pi^+$, $\rho^0 \to \pi^+\pi^-$		$(3.0\pm2.0)\times10^{-4}$		421
$\pi^+2\pi^0$		$(6.5\pm1.3)\times10^{-3}$		961
$2\pi^+\pi^-\pi^0$		—		935
$\eta\pi^+$	[ooo]	(1.70 ± 0.09) %	S=1.1	902
$\omega\pi^+$	[ooo]	$(2.4\pm0.6)\times10^{-3}$		822
$3\pi^+2\pi^-$		$(8.0\pm0.8)\times10^{-3}$		899
$2\pi^+\pi^-2\pi^0$		—		902
$\eta\rho^+$	[ooo]	(8.9 ± 0.8) %		724
$\eta\pi^+\pi^0$		(9.2 ± 1.2) %		885
$\omega\pi^+\pi^0$	[ooo]	(2.8 ± 0.7) %		802
$3\pi^+2\pi^-\pi^0$		(4.9 ± 3.2) %		856
$\omega 2\pi^+\pi^-$	[ooo]	(1.6 ± 0.5) %		766
$\eta'(958)\pi^+$	[nnn,ooo]	(3.94 ± 0.25) %		743
$3\pi^+2\pi^-2\pi^0$		—		803
$\omega\eta\pi^+$	[ooo]	< 2.13 %	CL=90%	654
$\eta'(958)\rho^+$	[nnn,ooo]	(5.8 ± 1.5) %		465
$\eta'(958)\pi^+\pi^0$		(5.6 ± 0.8) %		720
$\eta'(958)\pi^+\pi^0$ nonresonant		< 5.1 %	CL=90%	720
Modes with one or three K's				
$K^+\pi^0$		$(6.3\pm2.1)\times10^{-4}$		917
$K^0_S\pi^+$		$(1.22\pm0.06)\times10^{-3}$		916
$K^+\eta$	[ooo]	$(1.77\pm0.35)\times10^{-3}$		835
$K^+\omega$	[ooo]	$< 2.4\times10^{-3}$	CL=90%	741
$K^+\eta'(958)$	[ooo]	$(1.8\pm0.6)\times10^{-3}$		646

$K^+\pi^+\pi^-$			$(6.6 \pm 0.4) \times 10^{-3}$		900
$K^+\rho^0$			$(2.5 \pm 0.4) \times 10^{-3}$		745
$K^+\rho(1450)^0$, $\rho^0 \to \pi^+\pi^-$			$(7.0 \pm 2.4) \times 10^{-4}$		–
$K^*(892)^0\pi^+$, $K^{*0} \to K^+\pi^-$			$(1.42 \pm 0.24) \times 10^{-3}$		775
$K^*(1410)^0\pi^+$, $K^{*0} \to K^+\pi^-$			$(1.24 \pm 0.29) \times 10^{-3}$		–
$K^*(1430)^0\pi^+$, $K^{*0} \to K^+\pi^-$			$(5.0 \pm 3.5) \times 10^{-4}$		–
$K^+\pi^+\pi^-$ nonresonant			$(1.04 \pm 0.34) \times 10^{-3}$		900
$K^0\pi^+\pi^0$			(1.00 ± 0.18) %		899
$K^0_S 2\pi^+\pi^-$			$(3.0 \pm 1.1) \times 10^{-3}$		870
$K^+\omega\pi^0$		[ooo]	$< 8.2 \times 10^{-3}$	CL=90%	684
$K^+\omega\pi^+\pi^-$		[ooo]	$< 5.4 \times 10^{-3}$	CL=90%	603
$K^+\omega\eta$		[ooo]	$< 7.9 \times 10^{-3}$	CL=90%	366
$2K^+K^-$			$(2.18 \pm 0.21) \times 10^{-4}$		628
ϕK^+, $\phi \to K^+K^-$			$(8.9 \pm 2.0) \times 10^{-5}$		–
Doubly Cabibbo-suppressed modes					
$2K^+\pi^-$			$(1.27 \pm 0.13) \times 10^{-4}$		805
$K^+K^*(892)^0$, $K^{*0} \to K^+\pi^-$			$(6.0 \pm 3.4) \times 10^{-5}$		–
Baryon-antibaryon mode					
$p\overline{n}$			$(1.3 \pm 0.4) \times 10^{-3}$		295
$\Delta C = 1$ weak neutral current (*C1*) modes, Lepton family number (*LF*), or Lepton number (*L*) violating modes					
$\pi^+e^+e^-$		[zz]	$< 1.3 \times 10^{-5}$	CL=90%	979
$\pi^+\phi$, $\phi \to e^+e^-$		[yy]	$(6 ^{+8}_{-4}) \times 10^{-6}$		–
$\pi^+\mu^+\mu^-$		[zz]	$< 4.1 \times 10^{-7}$	CL=90%	968
$K^+e^+e^-$	*C1*		$< 3.7 \times 10^{-6}$	CL=90%	922
$K^+\mu^+\mu^-$	*C1*		$< 2.1 \times 10^{-5}$	CL=90%	909
$K^*(892)^+\mu^+\mu^-$	*C1*		$< 1.4 \times 10^{-3}$	CL=90%	765
$\pi^+e^+\mu^-$	*LF*		$< 1.2 \times 10^{-5}$	CL=90%	976
$\pi^+e^-\mu^+$	*LF*		$< 2.0 \times 10^{-5}$	CL=90%	976
$K^+e^+\mu^-$	*LF*		$< 1.4 \times 10^{-5}$	CL=90%	919
$K^+e^-\mu^+$	*LF*		$< 9.7 \times 10^{-6}$	CL=90%	919
π^-2e^+	*L*		$< 4.1 \times 10^{-6}$	CL=90%	979
$\pi^-2\mu^+$	*L*		$< 1.2 \times 10^{-7}$	CL=90%	968
$\pi^-e^+\mu^+$	*L*		$< 8.4 \times 10^{-6}$	CL=90%	976
K^-2e^+	*L*		$< 5.2 \times 10^{-6}$	CL=90%	922
$K^-2\mu^+$	*L*		$< 1.3 \times 10^{-5}$	CL=90%	909
$K^-e^+\mu^+$	*L*		$< 6.1 \times 10^{-6}$	CL=90%	919
$K^*(892)^-2\mu^+$	*L*		$< 1.4 \times 10^{-3}$	CL=90%	765

$D_s^{*\pm}$

$I(J^P) = 0(?^?)$

J^P is natural, width and decay modes consistent with 1^-.

Mass $m = 2112.2 \pm 0.4$ MeV

$m_{D_s^{*\pm}} - m_{D_s^\pm} = 143.8 \pm 0.4$ MeV

Full width $\Gamma < 1.9$ MeV, CL = 90%

D_s^{*-} modes are charge conjugates of the modes below.

D_s^{*+} DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$D_s^+ \gamma$	(93.5 ± 0.7) %	139
$D_s^+ \pi^0$	$(\ 5.8 \pm 0.7)$ %	48
$D_s^+ e^+ e^-$	$(\ 6.7 \pm 1.6) \times 10^{-3}$	139

$D_{s0}^*(2317)^\pm$

$I(J^P) = 0(0^+)$
J, P need confirmation.

J^P is natural, low mass consistent with 0^+.

Mass $m = 2317.7 \pm 0.6$ MeV (S = 1.1)
$m_{D_{s0}^*(2317)^\pm} - m_{D_s^\pm} = 349.4 \pm 0.6$ MeV (S = 1.1)
Full width $\Gamma < 3.8$ MeV, CL = 95%

$D_{s1}(2460)^\pm$

$I(J^P) = 0(1^+)$

Mass $m = 2459.5 \pm 0.6$ MeV (S = 1.1)
$m_{D_{s1}(2460)^\pm} - m_{D_s^{*\pm}} = 347.3 \pm 0.7$ MeV (S = 1.2)
$m_{D_{s1}(2460)^\pm} - m_{D_s^\pm} = 491.2 \pm 0.6$ MeV (S = 1.1)
Full width $\Gamma < 3.5$ MeV, CL = 95%

$D_{s1}(2460)^-$ modes are charge conjugates of the modes below.

$D_{s1}(2460)^+$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$D_s^{*+} \pi^0$	(48 ± 11) %		297
$D_s^+ \gamma$	(18 ± 4) %		442
$D_s^+ \pi^+ \pi^-$	$(\ 4.3 \pm 1.3)$ %	S=1.1	363
$D_s^{*+} \gamma$	< 8 %	CL=90%	323
$D_{s0}^*(2317)^+ \gamma$	$(\ 3.7^{+5.0}_{-2.4})$ %		138

$D_{s1}(2536)^\pm$

$I(J^P) = 0(1^+)$
J, P need confirmation.

Mass $m = 2535.10 \pm 0.06$ MeV
Full width $\Gamma = 0.92 \pm 0.05$ MeV

$D_{s1}(2536)^-$ modes are charge conjugates of the modes below.

$D_{s1}(2536)^+$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$D^*(2010)^+ K^0$	0.85 ± 0.12		149
$(D^*(2010)^+ K^0)_{S-wave}$	0.61 ± 0.09		149
$D^+ \pi^- K^+$	0.028 ± 0.005		176
$D^*(2007)^0 K^+$	**DEFINED AS 1**		167
$D^+ K^0$	<0.34	90%	381
$D^0 K^+$	<0.12	90%	391

See Particle Listings for 2 decay modes that have been seen / not seen.

$D_{s2}^*(2573)$

$I(J^P) = 0(2^+)$

J^P is natural, width and decay modes consistent with 2^+.

Mass $m = 2569.1 \pm 0.8$ MeV (S = 2.4)
Full width $\Gamma = 16.9 \pm 0.8$ MeV

$D_{s1}^*(2700)^\pm$

$I(J^P) = 0(1^-)$

Mass $m = 2708.3^{+4.0}_{-3.4}$ MeV
Full width $\Gamma = 120 \pm 11$ MeV

BOTTOM MESONS $(B = \pm1)$

$B^+ = u\overline{b}$, $B^0 = d\overline{b}$, $\overline{B}^0 = \overline{d}\,b$, $B^- = \overline{u}\,b$, similarly for B^*'s

$B^\pm$

$I(J^P) = \frac{1}{2}(0^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B^\pm} = 5279.32 \pm 0.14$ MeV (S = 1.1)
Mean life $\tau_{B^\pm} = (1.638 \pm 0.004) \times 10^{-12}$ s
$c\tau = 491.1\ \mu$m

CP violation

$A_{CP}(B^+ \to J/\psi(1S)K^+) = (1.8 \pm 3.0) \times 10^{-3}$ (S = 1.5)
$A_{CP}(B^+ \to J/\psi(1S)\pi^+) = (1.8 \pm 1.2) \times 10^{-2}$ (S = 1.3)
$A_{CP}(B^+ \to J/\psi\rho^+) = -0.11 \pm 0.14$
$A_{CP}(B^+ \to J/\psi K^*(892)^+) = -0.048 \pm 0.033$
$A_{CP}(B^+ \to \eta_c K^+) = 0.01 \pm 0.07$ (S = 2.2)
$A_{CP}(B^+ \to \psi(2S)\pi^+) = 0.03 \pm 0.06$
$A_{CP}(B^+ \to \psi(2S)K^+) = 0.012 \pm 0.020$ (S = 1.5)
$A_{CP}(B^+ \to \psi(2S)K^*(892)^+) = 0.08 \pm 0.21$
$A_{CP}(B^+ \to \chi_{c1}(1P)\pi^+) = 0.07 \pm 0.18$
$A_{CP}(B^+ \to \chi_{c0}K^+) = -0.20 \pm 0.18$ (S = 1.5)
$A_{CP}(B^+ \to \chi_{c1}K^+) = -0.009 \pm 0.033$
$A_{CP}(B^+ \to \chi_{c1}K^*(892)^+) = 0.5 \pm 0.5$
$A_{CP}(B^+ \to D^0\ell^+\nu_\ell) = (-0.14 \pm 0.20) \times 10^{-2}$
$A_{CP}(B^+ \to \overline{D}^0\pi^+) = -0.007 \pm 0.007$
$A_{CP}(B^+ \to D_{CP(+1)}\pi^+) = -0.0080 \pm 0.0026$
$A_{CP}(B^+ \to D_{CP(-1)}\pi^+) = 0.017 \pm 0.026$
$A_{CP}([K^\mp\pi^\pm\pi^+\pi^-]_D\pi^+) = 0.02 \pm 0.05$
$A_{CP}(B^+ \to [\pi^+\pi^+\pi^-\pi^-]_D K^+) = 0.10 \pm 0.04$
$A_{CP}(B^+ \to [\pi^+\pi^-\pi^+\pi^-]_D K^*(892)^+) = 0.02 \pm 0.11$
$A_{CP}(B^+ \to \overline{D}^0 K^+) = -0.017 \pm 0.005$
$A_{CP}([K^\mp\pi^\pm\pi^+\pi^-]_D K^+) = -0.31 \pm 0.11$
$A_{CP}(B^+ \to [\pi^+\pi^+\pi^-\pi^-]_D\pi^+) = (-4 \pm 8) \times 10^{-3}$
$A_{CP}(B^+ \to [K^-\pi^+]_D K^+) = -0.58 \pm 0.21$

$A_{CP}(B^+ \to [K^-\pi^+\pi^0]_D K^+) = 0.07 \pm 0.30$ (S = 1.5)
$A_{CP}(B^+ \to [K^+K^-\pi^0]_D K^+) = 0.30 \pm 0.20$
$A_{CP}(B^+ \to [\pi^+\pi^-\pi^0]_D K^+) = 0.05 \pm 0.09$
$A_{CP}(B^+ \to \overline{D}^0 K^*(892)^+) = -0.007 \pm 0.019$
$A_{CP}(B^+ \to [K^-\pi^+]_{\overline{D}} K^*(892)^+) = -0.75 \pm 0.16$
$A_{CP}(B^+ \to [K^-\pi^+\pi^-\pi^+]_{\overline{D}} K^*(892)^+) = -0.45 \pm 0.25$
$A_{CP}(B^+ \to [K^-\pi^+]_D \pi^+) = 0.00 \pm 0.09$
$A_{CP}(B^+ \to [K^-\pi^+\pi^0]_D \pi^+) = 0.35 \pm 0.16$
$A_{CP}(B^+ \to [K^+K^-\pi^0]_D \pi^+) = -0.03 \pm 0.04$
$A_{CP}(B^+ \to [\pi^+\pi^-\pi^0]_D \pi^+) = -0.016 \pm 0.020$
$A_{CP}(B^+ \to [K^-\pi^+]_{(D\pi)} \pi^+) = -0.09 \pm 0.27$
$A_{CP}(B^+ \to [K^-\pi^+]_{(D\gamma)} \pi^+) = -0.7 \pm 0.6$
$A_{CP}(B^+ \to [K^-\pi^+]_{(D\pi)} K^+) = 0.8 \pm 0.4$
$A_{CP}(B^+ \to [K^-\pi^+]_{(D\gamma)} K^+) = 0.4 \pm 1.0$
$A_{CP}(B^+ \to [\pi^+\pi^-\pi^0]_D K^+) = -0.02 \pm 0.15$
$A_{CP}(B^+ \to [K^0_S K^+\pi^-]_D K^+) = 0.04 \pm 0.09$
$A_{CP}(B^+ \to [K^0_S K^-\pi^+]_D K^+) = 0.23 \pm 0.13$
$A_{CP}(B^+ \to [K^0_S K^-\pi^+]_D \pi^+) = -0.052 \pm 0.034$
$A_{CP}(B^+ \to [K^0_S K^+\pi^-]_D \pi^+) = -0.025 \pm 0.026$
$A_{CP}(B^+ \to [K^*(892)^- K^+]_D K^+) = 0.03 \pm 0.11$
$A_{CP}(B^+ \to [K^*(892)^+ K^-]_D K^+) = 0.34 \pm 0.21$
$A_{CP}(B^+ \to [K^*(892)^+ K^-]_D \pi^+) = -0.05 \pm 0.05$
$A_{CP}(B^+ \to [K^*(892)^- K^+]_D \pi^+) = -0.012 \pm 0.030$
$\boldsymbol{A_{CP}(B^+ \to D_{CP(+1)} K^+)} = 0.120 \pm 0.014$ (S = 1.4)
$A_{ADS}(B^+ \to D K^+) = -0.40 \pm 0.06$
$A_{ADS}(B^+ \to D\pi^+) = 0.100 \pm 0.032$
$A_{ADS}(B^+ \to [K^-\pi^+]_D K^+\pi^-\pi^+) = -0.33 \pm 0.35$
$A_{ADS}(B^+ \to [K^-\pi^+]_D \pi^+\pi^-\pi^+) = -0.01 \pm 0.09$
$A_{CP}(B^+ \to D_{CP(-1)} K^+) = -0.10 \pm 0.07$
$A_{CP}(B^+ \to [K^+K^-]_D K^+\pi^-\pi^+) = -0.04 \pm 0.06$
$A_{CP}(B^+ \to [\pi^+\pi^-]_D K^+\pi^-\pi^+) = -0.05 \pm 0.10$
$A_{CP}(B^+ \to [K^-\pi^+]_D K^+\pi^-\pi^+) = 0.013 \pm 0.023$
$A_{CP}(B^+ \to [K^+K^-]_D \pi^+\pi^-\pi^+) = -0.019 \pm 0.015$
$A_{CP}(B^+ \to [\pi^+\pi^-]_D \pi^+\pi^-\pi^+) = -0.013 \pm 0.019$
$A_{CP}(B^+ \to [K^-\pi^+]_D \pi^+\pi^-\pi^+) = -0.002 \pm 0.011$
$A_{CP}(B^+ \to \overline{D}^{*0}\pi^+) = 0.0010 \pm 0.0028$
$A_{CP}(B^+ \to (D^*_{CP(+1)})^0\pi^+) = 0.016 \pm 0.010$ (S = 1.2)
$A_{CP}(B^+ \to (D^*_{CP(-1)})^0\pi^+) = -0.09 \pm 0.05$
$A_{CP}(B^+ \to D^{*0} K^+) = -0.001 \pm 0.011$ (S = 1.1)
$A_{CP}(B^+ \to D^{*0}_{CP(+1)} K^+) = -0.11 \pm 0.08$ (S = 2.7)
$A_{CP}(B^+ \to D^*_{CP(-1)} K^+) = 0.07 \pm 0.10$
$A_{CP}(B^+ \to D_{CP(+1)} K^*(892)^+) = 0.08 \pm 0.06$
$A_{CP}(B^+ \to D_{CP(-1)} K^*(892)^+) = -0.23 \pm 0.22$
$A_{CP}(B^+ \to D^+_s \phi) = 0.0 \pm 0.4$
$A_{CP}(B^+ \to D^{*+}\overline{D}^{*0}) = -0.15 \pm 0.11$
$A_{CP}(B^+ \to D^{*+}\overline{D}^0) = -0.06 \pm 0.13$
$A_{CP}(B^+ \to D^+\overline{D}^{*0}) = 0.13 \pm 0.18$
$A_{CP}(B^+ \to D^+\overline{D}^0) = -0.03 \pm 0.07$
$A_{CP}(B^+ \to K^0_S\pi^+) = -0.017 \pm 0.016$

$A_{CP}(B^+ \to K^+\pi^0) = 0.037 \pm 0.021$
$A_{CP}(B^+ \to \eta' K^+) = 0.004 \pm 0.011$
$A_{CP}(B^+ \to \eta' K^*(892)^+) = -0.26 \pm 0.27$
$A_{CP}(B^+ \to \eta' K_0^*(1430)^+) = 0.06 \pm 0.20$
$A_{CP}(B^+ \to \eta' K_2^*(1430)^+) = 0.15 \pm 0.13$
$\boldsymbol{A_{CP}(B^+ \to \eta K^+)} = -0.37 \pm 0.08$
$A_{CP}(B^+ \to \eta K^*(892)^+) = 0.02 \pm 0.06$
$A_{CP}(B^+ \to \eta K_0^*(1430)^+) = 0.05 \pm 0.13$
$A_{CP}(B^+ \to \eta K_2^*(1430)^+) = -0.45 \pm 0.30$
$A_{CP}(B^+ \to \omega K^+) = -0.02 \pm 0.04$
$A_{CP}(B^+ \to \omega K^{*+}) = 0.29 \pm 0.35$
$A_{CP}(B^+ \to \omega (K\pi)_0^{*+}) = -0.10 \pm 0.09$
$A_{CP}(B^+ \to \omega K_2^*(1430)^+) = 0.14 \pm 0.15$
$A_{CP}(B^+ \to K^{*0}\pi^+) = -0.04 \pm 0.09$ (S = 2.1)
$A_{CP}(B^+ \to K^*(892)^+\pi^0) = -0.39 \pm 0.21$ (S = 1.6)
$\boldsymbol{A_{CP}(B^+ \to K^+\pi^-\pi^+)} = 0.027 \pm 0.008$
$A_{CP}(B^+ \to K^+K^-K^+ \text{nonresonant}) = 0.06 \pm 0.05$
$A_{CP}(B^+ \to f(980)^0 K^+) = -0.08 \pm 0.09$
$\boldsymbol{A_{CP}(B^+ \to f_2(1270) K^+)} = -0.68^{+0.19}_{-0.17}$
$A_{CP}(B^+ \to f_0(1500) K^+) = 0.28 \pm 0.30$
$A_{CP}(B^+ \to f_2'(1525)^0 K^+) = -0.08^{+0.05}_{-0.04}$
$\boldsymbol{A_{CP}(B^+ \to \rho^0 K^+)} = 0.37 \pm 0.10$
$A_{CP}(B^+ \to K^0\pi^+\pi^0) = 0.07 \pm 0.06$
$A_{CP}(B^+ \to K_0^*(1430)^0\pi^+) = 0.061 \pm 0.032$
$A_{CP}(B^+ \to K_0^*(1430)^+\pi^0) = 0.26^{+0.18}_{-0.14}$
$A_{CP}(B^+ \to K_2^*(1430)^0\pi^+) = 0.05^{+0.29}_{-0.24}$
$A_{CP}(B^+ \to K^+\pi^0\pi^0) = -0.06 \pm 0.07$
$A_{CP}(B^+ \to K^0\rho^+) = -0.03 \pm 0.15$
$A_{CP}(B^+ \to K^{*+}\pi^+\pi^-) = 0.07 \pm 0.08$
$A_{CP}(B^+ \to \rho^0 K^*(892)^+) = 0.31 \pm 0.13$
$A_{CP}(B^+ \to K^*(892)^+ f_0(980)) = -0.15 \pm 0.12$
$A_{CP}(B^+ \to a_1^+ K^0) = 0.12 \pm 0.11$
$A_{CP}(B^+ \to b_1^+ K^0) = -0.03 \pm 0.15$
$A_{CP}(B^+ \to K^*(892)^0\rho^+) = -0.01 \pm 0.16$
$A_{CP}(B^+ \to b_1^0 K^+) = -0.46 \pm 0.20$
$A_{CP}(B^+ \to \overline{K}^0 K^+) = 0.04 \pm 0.14$
$A_{CP}(B^+ \to K_S^0 K^+) = -0.21 \pm 0.14$
$A_{CP}(B^+ \to K^+K_S^0K_S^0) = 0.04^{+0.04}_{-0.05}$
$\boldsymbol{A_{CP}(B^+ \to K^+K^-\pi^+)} = -0.122 \pm 0.021$
$\boldsymbol{A_{CP}(B^+ \to K^+K^-K^+)} = -0.033 \pm 0.008$
$A_{CP}(B^+ \to \phi K^+) = 0.024 \pm 0.028$ (S = 2.3)
$A_{CP}(B^+ \to X_0(1550) K^+) = -0.04 \pm 0.07$
$A_{CP}(B^+ \to K^{*+}K^+K^-) = 0.11 \pm 0.09$
$A_{CP}(B^+ \to \phi K^*(892)^+) = -0.01 \pm 0.08$
$A_{CP}(B^+ \to \phi (K\pi)_0^{*+}) = 0.04 \pm 0.16$
$A_{CP}(B^+ \to \phi K_1(1270)^+) = 0.15 \pm 0.20$
$A_{CP}(B^+ \to \phi K_2^*(1430)^+) = -0.23 \pm 0.20$
$A_{CP}(B^+ \to K^+\phi\phi) = -0.10 \pm 0.08$
$A_{CP}(B^+ \to K^+[\phi\phi]_{\eta_c}) = 0.09 \pm 0.10$
$A_{CP}(B^+ \to K^*(892)^+\gamma) = 0.014 \pm 0.018$

$A_{CP}(B^+ \rightarrow \eta K^+ \gamma) = -0.12 \pm 0.07$
$A_{CP}(B^+ \rightarrow \phi K^+ \gamma) = -0.13 \pm 0.11$ (S = 1.1)
$A_{CP}(B^+ \rightarrow \rho^+ \gamma) = -0.11 \pm 0.33$
$A_{CP}(B^+ \rightarrow \pi^+ \pi^0) = 0.03 \pm 0.04$
$\boldsymbol{A_{CP}(B^+ \rightarrow \pi^+ \pi^- \pi^+)} = 0.057 \pm 0.013$
$A_{CP}(B^+ \rightarrow \rho^0 \pi^+) = 0.18^{+0.09}_{-0.17}$
$A_{CP}(B^+ \rightarrow f_2(1270) \pi^+) = 0.41 \pm 0.30$
$A_{CP}(B^+ \rightarrow \rho^0(1450) \pi^+) = -0.1^{+0.4}_{-0.5}$
$\boldsymbol{A_{CP}(B^+ \rightarrow f_0(1370) \pi^+)} = 0.72 \pm 0.22$
$A_{CP}(B^+ \rightarrow \pi^+ \pi^- \pi^+ \text{ nonresonant}) = -0.14^{+0.23}_{-0.16}$
$A_{CP}(B^+ \rightarrow \rho^+ \pi^0) = 0.02 \pm 0.11$
$A_{CP}(B^+ \rightarrow \rho^+ \rho^0) = -0.05 \pm 0.05$
$A_{CP}(B^+ \rightarrow \omega \pi^+) = -0.04 \pm 0.06$
$A_{CP}(B^+ \rightarrow \omega \rho^+) = -0.20 \pm 0.09$
$A_{CP}(B^+ \rightarrow \eta \pi^+) = -0.14 \pm 0.07$ (S = 1.4)
$A_{CP}(B^+ \rightarrow \eta \rho^+) = 0.11 \pm 0.11$
$A_{CP}(B^+ \rightarrow \eta' \pi^+) = 0.06 \pm 0.16$
$A_{CP}(B^+ \rightarrow \eta' \rho^+) = 0.26 \pm 0.17$
$A_{CP}(B^+ \rightarrow b_1^0 \pi^+) = 0.05 \pm 0.16$
$A_{CP}(B^+ \rightarrow p \overline{p} \pi^+) = 0.00 \pm 0.04$
$A_{CP}(B^+ \rightarrow p \overline{p} K^+) = 0.00 \pm 0.04$ (S = 2.2)
$A_{CP}(B^+ \rightarrow p \overline{p} K^*(892)^+) = 0.21 \pm 0.16$ (S = 1.4)
$A_{CP}(B^+ \rightarrow p \overline{\Lambda} \gamma) = 0.17 \pm 0.17$
$A_{CP}(B^+ \rightarrow p \overline{\Lambda} \pi^0) = 0.01 \pm 0.17$
$A_{CP}(B^+ \rightarrow K^+ \ell^+ \ell^-) = -0.02 \pm 0.08$
$A_{CP}(B^+ \rightarrow K^+ e^+ e^-) = 0.14 \pm 0.14$
$A_{CP}(B^+ \rightarrow K^+ \mu^+ \mu^-) = 0.011 \pm 0.017$
$A_{CP}(B^+ \rightarrow \pi^+ \mu^+ \mu^-) = -0.11 \pm 0.12$
$A_{CP}(B^+ \rightarrow K^{*+} \ell^+ \ell^-) = -0.09 \pm 0.14$
$A_{CP}(B^+ \rightarrow K^* e^+ e^-) = -0.14 \pm 0.23$
$A_{CP}(B^+ \rightarrow K^* \mu^+ \mu^-) = -0.12 \pm 0.24$
$\gamma = (73.5^{+4.3}_{-5.0})^\circ$
$r_B(B^+ \rightarrow D^0 K^+) = 0.103 \pm 0.005$
$\delta_B(B^+ \rightarrow D^0 K^+) = (136.9^{+4.6}_{-5.2})^\circ$
$r_B(B^+ \rightarrow \overline{D}^0 K^{*+}) = 0.075^{+0.017}_{-0.018}$
$\delta_B(B^+ \rightarrow D^0 K^{*+}) = (106^{+18}_{-26})^\circ$
$r^*_B(B^+ \rightarrow D^{*0} K^+) = 0.142^{+0.019}_{-0.020}$
$\delta^*_B(B^+ \rightarrow D^{*0} K^+) = (321^{+8}_{-9})^\circ$

B^- modes are charge conjugates of the modes below. Modes which do not identify the charge state of the B are listed in the $B^\pm/B^0$ ADMIXTURE section.

The branching fractions listed below assume 50% $B^0 \overline{B}^0$ and 50% $B^+ B^-$ production at the $\Upsilon(4S)$. We have attempted to bring older measurements up to date by rescaling their assumed $\Upsilon(4S)$ production ratio to 50:50 and their assumed D, D_s, D^*, and ψ branching ratios to current values whenever this would affect our averages and best limits significantly.

Indentation is used to indicate a subchannel of a previous reaction. All resonant subchannels have been corrected for resonance branching fractions to the final state so the sum of the subchannel branching fractions can exceed that of the final state.

For inclusive branching fractions, *e.g.*, $B \to D^{\pm}$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

B^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Semileptonic and leptonic modes				
$\ell^+ \nu_\ell$ anything	[sss]	(10.99 ± 0.28) %		–
$e^+ \nu_e X_c$		(10.8 ± 0.4) %		–
$D \ell^+ \nu_\ell$ anything		(8.4 ± 0.5) %		–
$\overline{D}^0 \ell^+ \nu_\ell$	[sss]	(2.20 ± 0.10) %		2310
$\overline{D}^0 \tau^+ \nu_\tau$		(7.7 ± 2.5) $\times 10^{-3}$		1911
$\overline{D}^*(2007)^0 \ell^+ \nu_\ell$	[sss]	(4.88 ± 0.10) %		2258
$\overline{D}^*(2007)^0 \tau^+ \nu_\tau$		(1.88 ± 0.20) %		1839
$D^- \pi^+ \ell^+ \nu_\ell$		(4.1 ± 0.5) $\times 10^{-3}$		2306
$\overline{D}_0^*(2420)^0 \ell^+ \nu_\ell$, $\overline{D}_0^{*0} \to D^- \pi^+$		(2.5 ± 0.5) $\times 10^{-3}$		–
$\overline{D}_2^*(2460)^0 \ell^+ \nu_\ell$, $\overline{D}_2^{*0} \to D^- \pi^+$		(1.53 ± 0.16) $\times 10^{-3}$		2065
$D^{(*)} n\pi \ell^+ \nu_\ell (n \geq 1)$		(1.60 ± 0.22) %		–
$D^{*-} \pi^+ \ell^+ \nu_\ell$		(6.1 ± 0.6) $\times 10^{-3}$		2254
$\overline{D}_1(2420)^0 \ell^+ \nu_\ell$, $\overline{D}_1^0 \to D^{*-} \pi^+$		(3.03 ± 0.20) $\times 10^{-3}$		2084
$\overline{D}'_1(2430)^0 \ell^+ \nu_\ell$, $\overline{D}_1'^0 \to D^{*-} \pi^+$		(2.7 ± 0.6) $\times 10^{-3}$		–
$\overline{D}_2^*(2460)^0 \ell^+ \nu_\ell$, $\overline{D}_2^{*0} \to D^{*-} \pi^+$		(1.01 ± 0.24) $\times 10^{-3}$	S=2.0	2065
$\overline{D}^0 \pi^+ \pi^- \ell^+ \nu_\ell$		(1.56 ± 0.34) $\times 10^{-3}$		2301
$\overline{D}^{*0} \pi^+ \pi^- \ell^+ \nu_\ell$		(7 ± 4) $\times 10^{-4}$		2248
$D_s^{(*)-} K^+ \ell^+ \nu_\ell$		(6.1 ± 1.0) $\times 10^{-4}$		–
$D_s^- K^+ \ell^+ \nu_\ell$		(3.0 $^{+1.4}_{-1.2}$) $\times 10^{-4}$		2242
$D_s^{*-} K^+ \ell^+ \nu_\ell$		(2.9 ± 1.9) $\times 10^{-4}$		2185
$\pi^0 \ell^+ \nu_\ell$		(7.80 ± 0.27) $\times 10^{-5}$		2638
$\eta \ell^+ \nu_\ell$		(3.9 ± 0.5) $\times 10^{-5}$		2611
$\eta' \ell^+ \nu_\ell$		(2.3 ± 0.8) $\times 10^{-5}$		2553
$\omega \ell^+ \nu_\ell$	[sss]	(1.19 ± 0.09) $\times 10^{-4}$		2582
$\rho^0 \ell^+ \nu_\ell$	[sss]	(1.58 ± 0.11) $\times 10^{-4}$		2583
$p \overline{p} \ell^+ \nu_\ell$		(5.8 $^{+2.6}_{-2.3}$) $\times 10^{-6}$		2467
$p \overline{p} \mu^+ \nu_\mu$		< 8.5 $\times 10^{-6}$	CL=90%	2446
$p \overline{p} e^+ \nu_e$		(8.2 $^{+4.0}_{-3.3}$) $\times 10^{-6}$		2467
$e^+ \nu_e$		< 9.8 $\times 10^{-7}$	CL=90%	2640
$\mu^+ \nu_\mu$		< 1.0 $\times 10^{-6}$	CL=90%	2639
$\tau^+ \nu_\tau$		(1.09 ± 0.24) $\times 10^{-4}$	S=1.2	2341
$\ell^+ \nu_\ell \gamma$		< 3.5 $\times 10^{-6}$	CL=90%	2640
$e^+ \nu_e \gamma$		< 6.1 $\times 10^{-6}$	CL=90%	2640
$\mu^+ \nu_\mu \gamma$		< 3.4 $\times 10^{-6}$	CL=90%	2639
Inclusive modes				
$D^0 X$		(8.6 ± 0.7) %		–
$\overline{D}^0 X$		(79 ± 4) %		–
$D^+ X$		(2.5 ± 0.5) %		–
$D^- X$		(9.9 ± 1.2) %		–
$D_s^+ X$		(7.9 $^{+1.4}_{-1.3}$) %		–

$D_s^- X$		$(1.10 {}^{+0.40}_{-0.32})\%$		–
$\Lambda_c^+ X$		$(2.1 {}^{+0.9}_{-0.6})\%$		–
$\overline{\Lambda}_c^- X$		$(2.8 {}^{+1.1}_{-0.9})\%$		–
$\overline{c} X$		$(97 \pm 4)\%$		–
$c X$		$(23.4 {}^{+2.2}_{-1.8})\%$		–
$c/\overline{c} X$		$(120 \pm 6)\%$		–
D, D^*, or D_s modes				
$\overline{D}^0 \pi^+$		$(4.68 \pm 0.13) \times 10^{-3}$		2308
$D_{CP(+1)} \pi^+$	[ttt]	$(2.05 \pm 0.18) \times 10^{-3}$		–
$D_{CP(-1)} \pi^+$	[ttt]	$(2.0 \pm 0.4) \times 10^{-3}$		–
$\overline{D}^0 \rho^+$		$(1.34 \pm 0.18)\%$		2237
$\overline{D}^0 K^+$		$(3.63 \pm 0.12) \times 10^{-4}$		2281
$D_{CP(+1)} K^+$	[ttt]	$(1.80 \pm 0.07) \times 10^{-4}$		–
$D_{CP(-1)} K^+$	[ttt]	$(1.96 \pm 0.18) \times 10^{-4}$		–
$[K^- \pi^+]_D K^+$	[uuu]	$< 2.8 \times 10^{-7}$	CL=90%	–
$[K^+ \pi^-]_D K^+$	[uuu]	$< 1.5 \times 10^{-5}$	CL=90%	–
$[K^- \pi^+]_D \pi^+$	[uuu]	$(6.3 \pm 1.1) \times 10^{-7}$		–
$[K^+ \pi^-]_D \pi^+$		$(1.78 \pm 0.32) \times 10^{-4}$		–
$[\pi^+ \pi^- \pi^0]_D K^-$		$(4.6 \pm 0.9) \times 10^{-6}$		–
$\overline{D}^0 K^*(892)^+$		$(5.3 \pm 0.4) \times 10^{-4}$		2213
$D_{CP(-1)} K^*(892)^+$	[ttt]	$(2.7 \pm 0.8) \times 10^{-4}$		–
$D_{CP(+1)} K^*(892)^+$	[ttt]	$(6.2 \pm 0.6) \times 10^{-4}$		–
$\overline{D}^0 K^+ \pi^+ \pi^-$		$(5.2 \pm 2.1) \times 10^{-4}$		2237
$\overline{D}^0 K^+ \overline{K}^0$		$(5.5 \pm 1.6) \times 10^{-4}$		2189
$\overline{D}^0 K^+ \overline{K}^*(892)^0$		$(7.5 \pm 1.7) \times 10^{-4}$		2071
$\overline{D}^0 \pi^+ \pi^+ \pi^-$		$(5.6 \pm 2.1) \times 10^{-3}$	S=3.6	2289
$\overline{D}^0 \pi^+ \pi^+ \pi^-$ nonresonant		$(5 \pm 4) \times 10^{-3}$		2289
$\overline{D}^0 \pi^+ \rho^0$		$(4.2 \pm 3.0) \times 10^{-3}$		2208
$\overline{D}^0 a_1(1260)^+$		$(4 \pm 4) \times 10^{-3}$		2123
$\overline{D}^0 \omega \pi^+$		$(4.1 \pm 0.9) \times 10^{-3}$		2206
$D^*(2010)^- \pi^+ \pi^+$		$(1.35 \pm 0.22) \times 10^{-3}$		2247
$D^*(2010)^- K^+ \pi^+$		$(8.2 \pm 1.4) \times 10^{-5}$		2206
$\overline{D}_1(2420)^0 \pi^+$, $\overline{D}_1^0 \to D^*(2010)^- \pi^+$		$(5.2 \pm 2.2) \times 10^{-4}$		2081
$D^- \pi^+ \pi^+$		$(1.07 \pm 0.05) \times 10^{-3}$		2299
$D^- K^+ \pi^+$		$(7.7 \pm 0.5) \times 10^{-5}$		2260
$D_0^*(2400)^0 K^+$, $D_0^{*0} \to D^- \pi^+$		$(6.1 \pm 2.4) \times 10^{-6}$		–
$D_2^*(2460)^0 K^+$, $D_2^{*0} \to D^- \pi^+$		$(2.32 \pm 0.23) \times 10^{-5}$		–
$D_1^*(2760)^0 K^+$, $D_1^{*0} \to D^- \pi^+$		$(3.6 \pm 1.2) \times 10^{-6}$		–
$D^+ K^0$		$< 2.9 \times 10^{-6}$	CL=90%	2278
$D^+ K^+ \pi^-$		$(5.6 \pm 1.1) \times 10^{-6}$		2260
$D_2^*(2460)^0 K^+$, $D_2^{*0} \to D^+ \pi^-$		$< 6.3 \times 10^{-7}$	CL=90%	–
$D^+ K^{*0}$		$< 4.9 \times 10^{-7}$	CL=90%	2211
$D^+ \overline{K}^{*0}$		$< 1.4 \times 10^{-6}$	CL=90%	2211
$\overline{D}^*(2007)^0 \pi^+$		$(4.90 \pm 0.17) \times 10^{-3}$		2256
$\overline{D}^{*0}_{CP(+1)} \pi^+$	[vvv]	$(2.7 \pm 0.6) \times 10^{-3}$		–
$D^{*0}_{CP(-1)} \pi^+$	[vvv]	$(2.4 \pm 0.9) \times 10^{-3}$		–

$\overline{D}^*(2007)^0 \omega \pi^+$		$(4.5 \pm 1.2) \times 10^{-3}$		2149
$\overline{D}^*(2007)^0 \rho^+$		$(9.8 \pm 1.7) \times 10^{-3}$		2181
$\overline{D}^*(2007)^0 K^+$		$(3.97 {}^{+0.31}_{-0.28}) \times 10^{-4}$		2227
$\quad \overline{D}^{*0}_{CP(+1)} K^+$	[vvv]	$(2.60 \pm 0.33) \times 10^{-4}$		–
$\quad \overline{D}^{*0}_{CP(-1)} K^+$	[vvv]	$(2.19 \pm 0.30) \times 10^{-4}$		–
$\overline{D}^*(2007)^0 K^*(892)^+$		$(8.1 \pm 1.4) \times 10^{-4}$		2156
$\overline{D}^*(2007)^0 K^+ \overline{K}^0$		$< 1.06 \times 10^{-3}$	CL=90%	2132
$\overline{D}^*(2007)^0 K^+ \overline{K}^*(892)^0$		$(1.5 \pm 0.4) \times 10^{-3}$		2009
$\overline{D}^*(2007)^0 \pi^+ \pi^+ \pi^-$		(1.03 ± 0.12) %		2236
$\quad \overline{D}^*(2007)^0 a_1(1260)^+$		(1.9 ± 0.5) %		2063
$\overline{D}^*(2007)^0 \pi^- \pi^+ \pi^+ \pi^0$		(1.8 ± 0.4) %		2219
$\overline{D}^{*0} 3\pi^+ 2\pi^-$		$(5.7 \pm 1.2) \times 10^{-3}$		2196
$D^*(2010)^+ \pi^0$		$< 3.6 \times 10^{-6}$		2255
$D^*(2010)^+ K^0$		$< 9.0 \times 10^{-6}$	CL=90%	2225
$D^*(2010)^- \pi^+ \pi^+ \pi^0$		(1.5 ± 0.7) %		2235
$D^*(2010)^- \pi^+ \pi^+ \pi^+ \pi^-$		$(2.6 \pm 0.4) \times 10^{-3}$		2217
$\overline{D}^{**0} \pi^+$	[xxx]	$(5.7 \pm 1.2) \times 10^{-3}$		–
$\overline{D}^*_1(2420)^0 \pi^+$		$(1.5 \pm 0.6) \times 10^{-3}$	S=1.3	2082
$\overline{D}_1(2420)^0 \pi^+ \times$ B$(\overline{D}^0_1 \to \overline{D}^0 \pi^+ \pi^-)$		$(2.5 {}^{+1.6}_{-1.4}) \times 10^{-4}$	S=3.9	2082
$\quad \overline{D}_1(2420)^0 \pi^+ \times$ B$(\overline{D}^0_1 \to \overline{D}^0 \pi^+ \pi^-$ (nonresonant))		$(2.2 \pm 1.0) \times 10^{-4}$		2082
$\overline{D}^*_2(2462)^0 \pi^+ \times$ B$(\overline{D}^*_2(2462)^0 \to D^- \pi^+)$		$(3.56 \pm 0.24) \times 10^{-4}$		–
$\overline{D}^*_2(2462)^0 \pi^+ \times$B$(\overline{D}^{*0}_2 \to \overline{D}^0 \pi^- \pi^+)$		$(2.2 \pm 1.0) \times 10^{-4}$		–
$\quad \overline{D}^*_2(2462)^0 \pi^+ \times$B$(\overline{D}^{*0}_2 \to \overline{D}^0 \pi^- \pi^+$ (nonresonant))		$< 1.7 \times 10^{-4}$	CL=90%	–
$\overline{D}^*_2(2462)^0 \pi^+ \times$B$(\overline{D}^{*0}_2 \to D^*(2010)^- \pi^+)$		$(2.2 \pm 1.1) \times 10^{-4}$		–
$\overline{D}^*_0(2400)^0 \pi^+ \times$ B$(\overline{D}^*_0(2400)^0 \to D^- \pi^+)$		$(6.4 \pm 1.4) \times 10^{-4}$		2128
$\overline{D}_1(2421)^0 \pi^+ \times$ B$(\overline{D}_1(2421)^0 \to D^{*-} \pi^+)$		$(6.8 \pm 1.5) \times 10^{-4}$		–
$\overline{D}^*_2(2462)^0 \pi^+ \times$ B$(\overline{D}^*_2(2462)^0 \to D^{*-} \pi^+)$		$(1.8 \pm 0.5) \times 10^{-4}$		–
$\overline{D}'_1(2427)^0 \pi^+ \times$ B$(\overline{D}'_1(2427)^0 \to D^{*-} \pi^+)$		$(5.0 \pm 1.2) \times 10^{-4}$		–
$\overline{D}_1(2420)^0 \pi^+ \times$B$(\overline{D}^0_1 \to \overline{D}^{*0} \pi^+ \pi^-)$		$< 6 \times 10^{-6}$	CL=90%	2082
$\overline{D}^*_1(2420)^0 \rho^+$		$< 1.4 \times 10^{-3}$	CL=90%	1996
$\overline{D}^*_2(2460)^0 \pi^+$		$< 1.3 \times 10^{-3}$	CL=90%	2063
$\overline{D}^*_2(2460)^0 \pi^+ \times$B$(\overline{D}^{*0}_2 \to \overline{D}^{*0} \pi^+ \pi^-)$		$< 2.2 \times 10^{-5}$	CL=90%	2063
$\overline{D}^*_1(2680)^0 \pi^+$, $\overline{D}^*_1(2680)^0 \to D^- \pi^+$		$(8.4 \pm 2.1) \times 10^{-5}$		–
$\overline{D}^*_3(2760)^0 \pi^+$, $\overline{D}^*_3(2760)^0 \pi^+ \to D^- \pi^+$		$(1.00 \pm 0.22) \times 10^{-5}$		–
$\overline{D}^*_2(3000)^0 \pi^+$, $\overline{D}^*_2(3000)^0 \pi^+ \to D^- \pi^+$		$(2.0 \pm 1.4) \times 10^{-6}$		–
$\overline{D}^*_2(2460)^0 \rho^+$		$< 4.7 \times 10^{-3}$	CL=90%	1977

$\overline{D}^0 D_s^+$	$(9.0 \pm 0.9) \times 10^{-3}$		1815
$D_{s0}^*(2317)^+ \overline{D}^0$, $D_{s0}^{*+} \rightarrow D_s^+ \pi^0$	$(7.9 {}^{+1.5}_{-1.3}) \times 10^{-4}$		1605
$D_{s0}(2317)^+ \overline{D}^0 \times$ B$(D_{s0}(2317)^+ \rightarrow D_s^{*+} \gamma)$	$< 7.6 \times 10^{-4}$	CL=90%	1605
$D_{s0}(2317)^+ \overline{D}^*(2007)^0 \times$ B$(D_{s0}(2317)^+ \rightarrow D_s^+ \pi^0)$	$(9 \pm 7) \times 10^{-4}$		1511
$D_{sJ}(2457)^+ \overline{D}^0$	$(3.1 {}^{+1.0}_{-0.9}) \times 10^{-3}$		–
$D_{sJ}(2457)^+ \overline{D}^0 \times$ B$(D_{sJ}(2457)^+ \rightarrow D_s^+ \gamma)$	$(4.6 {}^{+1.3}_{-1.1}) \times 10^{-4}$		–
$D_{sJ}(2457)^+ \overline{D}^0 \times$ B$(D_{sJ}(2457)^+ \rightarrow D_s^+ \pi^+ \pi^-)$	$< 2.2 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+ \overline{D}^0 \times$ B$(D_{sJ}(2457)^+ \rightarrow D_s^+ \pi^0)$	$< 2.7 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+ \overline{D}^0 \times$ B$(D_{sJ}(2457)^+ \rightarrow D_s^{*+} \gamma)$	$< 9.8 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+ \overline{D}^*(2007)^0$	(1.20 ± 0.30) %		–
$D_{sJ}(2457)^+ \overline{D}^*(2007)^0 \times$ B$(D_{sJ}(2457)^+ \rightarrow D_s^+ \gamma)$	$(1.4 {}^{+0.7}_{-0.6}) \times 10^{-3}$		–
$\overline{D}^0 D_{s1}(2536)^+ \times$ B$(D_{s1}(2536)^+ \rightarrow D^*(2007)^0 K^+ + D^*(2010)^+ K^0)$	$(4.0 \pm 1.0) \times 10^{-4}$		1447
$\overline{D}^0 D_{s1}(2536)^+ \times$ B$(D_{s1}(2536)^+ \rightarrow D^*(2007)^0 K^+)$	$(2.2 \pm 0.7) \times 10^{-4}$		1447
$\overline{D}^*(2007)^0 D_{s1}(2536)^+ \times$ B$(D_{s1}(2536)^+ \rightarrow D^*(2007)^0 K^+)$	$(5.5 \pm 1.6) \times 10^{-4}$		1339
$\overline{D}^0 D_{s1}(2536)^+ \times$ B$(D_{s1}(2536)^+ \rightarrow D^{*+} K^0)$	$(2.3 \pm 1.1) \times 10^{-4}$		1447
$\overline{D}^0 D_{sJ}(2700)^+ \times$ B$(D_{sJ}(2700)^+ \rightarrow D^0 K^+)$	$(5.6 \pm 1.8) \times 10^{-4}$	S=1.7	–
$\overline{D}^{*0} D_{s1}(2536)^+$, $D_{s1}^+ \rightarrow D^{*+} K^0$	$(3.9 \pm 2.6) \times 10^{-4}$		1339
$\overline{D}^0 D_{sJ}(2573)^+$, $D_{sJ}^+ \rightarrow D^0 K^+$	$(8 \pm 15) \times 10^{-6}$		–
$\overline{D}^{*0} D_{sJ}(2573)$, $D_{sJ}^+ \rightarrow D^0 K^+$	$< 2 \times 10^{-4}$	CL=90%	1306
$\overline{D}^*(2007)^0 D_{sJ}(2573)$, $D_{sJ}^+ \rightarrow D^0 K^+$	$< 5 \times 10^{-4}$	CL=90%	1306
$\overline{D}^0 D_s^{*+}$	$(7.6 \pm 1.6) \times 10^{-3}$		1734
$\overline{D}^*(2007)^0 D_s^+$	$(8.2 \pm 1.7) \times 10^{-3}$		1737
$\overline{D}^*(2007)^0 D_s^{*+}$	(1.71 ± 0.24) %		1651
$D_s^{(*)+} \overline{D}^{**0}$	(2.7 ± 1.2) %		–
$\overline{D}^*(2007)^0 D^*(2010)^+$	$(8.1 \pm 1.7) \times 10^{-4}$		1713
$\overline{D}^0 D^*(2010)^+ + \overline{D}^*(2007)^0 D^+$	< 1.30 %	CL=90%	1792
$\overline{D}^0 D^*(2010)^+$	$(3.9 \pm 0.5) \times 10^{-4}$		1792
$\overline{D}^0 D^+$	$(3.8 \pm 0.4) \times 10^{-4}$		1866
$\overline{D}^0 D^+ K^0$	$(1.55 \pm 0.21) \times 10^{-3}$		1571
$D^+ \overline{D}^*(2007)^0$	$(6.3 \pm 1.7) \times 10^{-4}$		1791
$\overline{D}^*(2007)^0 D^+ K^0$	$(2.1 \pm 0.5) \times 10^{-3}$		1475
$\overline{D}^0 D^*(2010)^+ K^0$	$(3.8 \pm 0.4) \times 10^{-3}$		1476

$\overline{D}^*(2007)^0 D^*(2010)^+ K^0$	(9.2 ± 1.2) × 10^{-3}			1362
$\overline{D}^0 D^0 K^+$	(1.45 ± 0.33) × 10^{-3}		S=2.6	1577
$\overline{D}^*(2007)^0 D^0 K^+$	(2.26 ± 0.23) × 10^{-3}			1481
$\overline{D}^0 D^*(2007)^0 K^+$	(6.3 ± 0.5) × 10^{-3}			1481
$\overline{D}^*(2007)^0 D^*(2007)^0 K^+$	(1.12 ± 0.13) %			1368
$D^- D^+ K^+$	(2.2 ± 0.7) × 10^{-4}			1571
$D^- D^*(2010)^+ K^+$	(6.3 ± 1.1) × 10^{-4}			1475
$D^*(2010)^- D^+ K^+$	(6.0 ± 1.3) × 10^{-4}			1475
$D^*(2010)^- D^*(2010)^+ K^+$	(1.32 ± 0.18) × 10^{-3}			1363
$(\overline{D}+\overline{D}^*)(D+D^*)K$	(4.05 ± 0.30) %			–
$D_s^+ \pi^0$	(1.6 ± 0.5) × 10^{-5}			2270
$D_s^{*+} \pi^0$	< 2.6	× 10^{-4}	CL=90%	2215
$D_s^+ \eta$	< 4	× 10^{-4}	CL=90%	2235
$D_s^{*+} \eta$	< 6	× 10^{-4}	CL=90%	2178
$D_s^+ \rho^0$	< 3.0	× 10^{-4}	CL=90%	2197
$D_s^{*+} \rho^0$	< 4	× 10^{-4}	CL=90%	2138
$D_s^+ \omega$	< 4	× 10^{-4}	CL=90%	2195
$D_s^{*+} \omega$	< 6	× 10^{-4}	CL=90%	2136
$D_s^+ a_1(1260)^0$	< 1.8	× 10^{-3}	CL=90%	2079
$D_s^{*+} a_1(1260)^0$	< 1.3	× 10^{-3}	CL=90%	2015
$D_s^+ K^+ K^-$	(7.1 ± 1.1) × 10^{-6}			2149
$D_s^+ \phi$	< 4.2	× 10^{-7}	CL=90%	2141
$D_s^{*+} \phi$	< 1.2	× 10^{-5}	CL=90%	2079
$D_s^+ \overline{K}^0$	< 8	× 10^{-4}	CL=90%	2242
$D_s^{*+} \overline{K}^0$	< 9	× 10^{-4}	CL=90%	2185
$D_s^+ \overline{K}^*(892)^0$	< 4.4	× 10^{-6}	CL=90%	2172
$D_s^+ K^{*0}$	< 3.5	× 10^{-6}	CL=90%	2172
$D_s^{*+} \overline{K}^*(892)^0$	< 3.5	× 10^{-4}	CL=90%	2112
$D_s^- \pi^+ K^+$	(1.80 ± 0.22) × 10^{-4}			2222
$D_s^{*-} \pi^+ K^+$	(1.45 ± 0.24) × 10^{-4}			2164
$D_s^- \pi^+ K^*(892)^+$	< 5	× 10^{-3}	CL=90%	2138
$D_s^{*-} \pi^+ K^*(892)^+$	< 7	× 10^{-3}	CL=90%	2076
$D_s^- K^+ K^+$	(9.7 ± 2.1) × 10^{-6}			2149
$D_s^{*-} K^+ K^+$	< 1.5	× 10^{-5}	CL=90%	2088

Charmonium modes

$\eta_c K^+$	(1.09 ± 0.09) × 10^{-3}		S=1.1	1751
$\eta_c K^+$, $\eta_c \to K_S^0 K^\mp \pi^\pm$	(2.7 ± 0.6) × 10^{-5}			–
$\eta_c K^*(892)^+$	(1.0 $^{+0.5}_{-0.4}$) × 10^{-3}			1646
$\eta_c K^+ \pi^+ \pi^-$	< 3.9	× 10^{-4}	CL=90%	1684
$\eta_c K^+ \omega(782)$	< 5.3	× 10^{-4}	CL=90%	1475
$\eta_c K^+ \eta$	< 2.2	× 10^{-4}	CL=90%	1588
$\eta_c K^+ \pi^0$	< 6.2	× 10^{-5}	CL=90%	1723
$\eta_c(2S) K^+$	(4.4 ± 1.0) × 10^{-4}			1320
$\eta_c(2S) K^+$, $\eta_c \to p\overline{p}$	(3.5 ± 0.8) × 10^{-8}			–
$\eta_c(2S) K^+$, $\eta_c \to K_S^0 K^\mp \pi^\pm$	(3.4 $^{+2.3}_{-1.6}$) × 10^{-6}			–
$h_c(1P) K^+$, $h_c \to J/\psi \pi^+ \pi^-$	< 3.4	× 10^{-6}	CL=90%	1401
$X(3730)^0 K^+$, $X^0 \to \eta_c \eta$	< 4.6	× 10^{-5}	CL=90%	–
$X(3730)^0 K^+$, $X^0 \to \eta_c \pi^0$	< 5.7	× 10^{-6}	CL=90%	–
$\chi_{c1}(3872) K^+$	< 2.6	× 10^{-4}	CL=90%	1141
$\chi_{c1}(3872) K^+$, $\chi_{c1} \to p\overline{p}$	< 5	× 10^{-9}	CL=95%	–

$\chi_{c1}(3872)K^+$, $\chi_{c1} \to J/\psi\pi^+\pi^-$		(8.6 ± 0.8) $\times 10^{-6}$			1141
$\chi_{c1}(3872)K^+$, $\chi_{c1} \to J/\psi\gamma$		(2.1 ± 0.4) $\times 10^{-6}$		S=1.1	1141
$\chi_{c1}(3872)K^+$, $\chi_{c1} \to \psi(2S)\gamma$		(4 ± 4) $\times 10^{-6}$		S=2.5	1141
$\chi_{c1}(3872)K^+$, $\chi_{c1} \to J/\psi(1S)\eta$		< 7.7 $\times 10^{-6}$		CL=90%	1141
$\chi_{c1}(3872)K^+$, $\chi_{c1} \to D^0\overline{D}^0$		< 6.0 $\times 10^{-5}$		CL=90%	1141
$\chi_{c1}(3872)K^+$, $\chi_{c1} \to D^+D^-$		< 4.0 $\times 10^{-5}$		CL=90%	1141
$\chi_{c1}(3872)K^+$, $\chi_{c1} \to D^0\overline{D}^0\pi^0$		(1.0 ± 0.4) $\times 10^{-4}$			1141
$\chi_{c1}(3872)K^+$, $\chi_{c1} \to \overline{D}^{*0}D^0$		(8.5 ± 2.6) $\times 10^{-5}$		S=1.4	1141
$\chi_{c1}(3872)^0K^+$, $\chi_{c1}^0 \to \eta_c\pi^+\pi^-$		< 3.0 $\times 10^{-5}$		CL=90%	–
$\chi_{c1}(3872)^0K^+$, $\chi_{c1}^0 \to \eta_c\omega(782)$		< 6.9 $\times 10^{-5}$		CL=90%	–
$\chi_{c1}(3872)K^+$, $\chi_{c1} \to \chi_{c1}(1P)\pi^+\pi^-$		< 1.5 $\times 10^{-6}$		CL=90%	–
$X(3915)K^+$		< 2.8 $\times 10^{-4}$		CL=90%	1103
$X(3915)^0K^+$, $X^0 \to \eta_c\eta$		< 4.7 $\times 10^{-5}$		CL=90%	–
$X(3915)^0K^+$, $X^0 \to \eta_c\pi^0$		< 1.7 $\times 10^{-5}$		CL=90%	–
$X(4014)^0K^+$, $X^0 \to \eta_c\eta$		< 3.9 $\times 10^{-5}$		CL=90%	–
$X(4014)^0K^+$, $X^0 \to \eta_c\pi^0$		< 1.2 $\times 10^{-5}$		CL=90%	–
$Z_c(3900)^0K^+$, $Z_c^0 \to \eta_c\pi^+\pi^-$		< 4.7 $\times 10^{-5}$		CL=90%	–
$X(4020)^0K^+$, $X^0 \to \eta_c\pi^+\pi^-$		< 1.6 $\times 10^{-5}$		CL=90%	–
$\chi_{c1}(3872)K^*(892)^+$, $\chi_{c1} \to J/\psi\gamma$		< 4.8 $\times 10^{-6}$		CL=90%	939
$\chi_{c1}(3872)K^*(892)^+$, $\chi_{c1} \to \psi(2S)\gamma$		< 2.8 $\times 10^{-5}$		CL=90%	939
$\chi_{c1}(3872)^+K^0$, $\chi_{c1}^+ \to J/\psi(1S)\pi^+\pi^0$	[yyy]	< 6.1 $\times 10^{-6}$		CL=90%	–
$\chi_{c1}(3872)K^0\pi^+$, $\chi_{c1} \to J/\psi(1S)\pi^+\pi^-$		(1.06 ± 0.31) $\times 10^{-5}$			–
$Z_c(4430)^+K^0$, $Z_c^+ \to J/\psi\pi^+$		< 1.5 $\times 10^{-5}$		CL=95%	–
$Z_c(4430)^+K^0$, $Z_c^+ \to \psi(2S)\pi^+$		< 4.7 $\times 10^{-5}$		CL=95%	–
$\psi(4260)^0K^+$, $\psi^0 \to J/\psi\pi^+\pi^-$		< 2.9 $\times 10^{-5}$		CL=95%	–
$X(3915)K^+$, $X \to J/\psi\gamma$		< 1.4 $\times 10^{-5}$		CL=90%	–
$X(3930)^0K^+$, $X^0 \to J/\psi\gamma$		< 2.5 $\times 10^{-6}$		CL=90%	–
$J/\psi(1S)K^+$		(1.010± 0.029) $\times 10^{-3}$			1684
$J/\psi(1S)K^0\pi^+$		(1.14 ± 0.11) $\times 10^{-3}$			1651
$J/\psi(1S)K^+\pi^+\pi^-$		(8.1 ± 1.3) $\times 10^{-4}$		S=2.5	1612
$J/\psi(1S)K^+K^-K^+$		(3.37 ± 0.29) $\times 10^{-5}$			1252
$X(3915)K^+$, $X \to p\overline{p}$		< 7.1 $\times 10^{-8}$		CL=95%	–
$J/\psi(1S)K^*(892)^+$		(1.43 ± 0.08) $\times 10^{-3}$			1571
$J/\psi(1S)K(1270)^+$		(1.8 ± 0.5) $\times 10^{-3}$			1390
$J/\psi(1S)K(1400)^+$		< 5 $\times 10^{-4}$		CL=90%	1308
$J/\psi(1S)\eta K^+$		(1.24 ± 0.14) $\times 10^{-4}$			1510
$\chi_{c1-odd}(3872)K^+$, $\chi_{c1-odd} \to J/\psi\eta$		< 3.8 $\times 10^{-6}$		CL=90%	–
$\psi(4160)K^+$, $\psi \to J/\psi\eta$		< 7.4 $\times 10^{-6}$		CL=90%	–
$J/\psi(1S)\eta' K^+$		< 8.8 $\times 10^{-5}$		CL=90%	1273
$J/\psi(1S)\phi K^+$		(5.0 ± 0.4) $\times 10^{-5}$			1227

$J/\psi(1S)\,K_1(1650)$, $K_1 \to \phi K^+$	$(6\ {}^{+10}_{-6}) \times 10^{-6}$			–
$J/\psi(1S)\,K^*(1680)^+$, $K^* \to \phi K^+$	$(3.4\ {}^{+1.9}_{-2.2}) \times 10^{-6}$			–
$J/\psi(1S)\,K_2^*(1980)$, $K_2^* \to \phi K^+$	$(1.5\ {}^{+0.9}_{-0.5}) \times 10^{-6}$			–
$J/\psi(1S)\,K(1830)^+$, $K(1830)^+ \to \phi K^+$	$(1.3\ {}^{+1.3}_{-1.1}) \times 10^{-6}$			–
$\chi_{c1}(4140)\,K^+$, $\chi_{c1} \to J/\psi(1S)\phi$	$(10 \pm 4) \times 10^{-6}$			–
$\chi_{c1}(4274)\,K^+$, $\chi_{c1} \to J/\psi(1S)\phi$	$(3.6\ {}^{+2.2}_{-1.8}) \times 10^{-6}$			–
$\chi_{c0}(4500)\,K^+$, $\chi_c^0 \to J/\psi(1S)\phi$	$(3.3\ {}^{+2.1}_{-1.7}) \times 10^{-6}$			–
$\chi_{c0}(4700)\,K^+$, $\chi_{c0} \to J/\psi(1S)\phi$	$(6\ {}^{+5}_{-4}) \times 10^{-6}$			–
$J/\psi(1S)\,\omega K^+$	$(3.20\ {}^{+0.60}_{-0.32}) \times 10^{-4}$			1388
$\chi_{c1}(3872)\,K^+$, $\chi_{c1} \to J/\psi\omega$	$(6.0 \pm 2.2) \times 10^{-6}$			1141
$X(3915)\,K^+$, $X \to J/\psi\omega$	$(3.0\ {}^{+0.9}_{-0.7}) \times 10^{-5}$			1103
$J/\psi(1S)\,\pi^+$	$(3.88 \pm 0.12) \times 10^{-5}$			1728
$J/\psi(1S)\,\pi^+\pi^+\pi^+\pi^-\pi^-$	$(1.17 \pm 0.13) \times 10^{-5}$			1635
$\psi(2S)\,\pi^+\pi^+\pi^-$	$(1.9 \pm 0.4) \times 10^{-5}$			1304
$J/\psi(1S)\,\rho^+$	$(5.0 \pm 0.8) \times 10^{-5}$			1611
$J/\psi(1S)\,\pi^+\pi^0$ nonresonant	$< 7.3 \times 10^{-6}$	CL=90%		1717
$J/\psi(1S)\,a_1(1260)^+$	$< 1.2 \times 10^{-3}$	CL=90%		1415
$J/\psi(1S)\,p\overline{p}\pi^+$	$< 5.0 \times 10^{-7}$	CL=90%		643
$J/\psi(1S)\,p\overline{\Lambda}$	$(1.18 \pm 0.31) \times 10^{-5}$			567
$J/\psi(1S)\,\overline{\Sigma}^0 p$	$< 1.1 \times 10^{-5}$	CL=90%		–
$J/\psi(1S)\,D^+$	$< 1.2 \times 10^{-4}$	CL=90%		871
$J/\psi(1S)\,\overline{D}^0\pi^+$	$< 2.5 \times 10^{-5}$	CL=90%		665
$\psi(2S)\,\pi^+$	$(2.44 \pm 0.30) \times 10^{-5}$			1347
$\psi(2S)\,K^+$	$(6.21 \pm 0.23) \times 10^{-4}$			1284
$\psi(2S)\,K^*(892)^+$	$(6.7 \pm 1.4) \times 10^{-4}$	S=1.3		1115
$\psi(2S)\,K^+\pi^+\pi^-$	$(4.3 \pm 0.5) \times 10^{-4}$			1179
$\psi(2S)\,\phi(1020)\,K^+$	$(4.0 \pm 0.7) \times 10^{-6}$			417
$\psi(3770)\,K^+$	$(4.9 \pm 1.3) \times 10^{-4}$			1218
$\psi(3770)\,K+, \psi \to D^0\overline{D}^0$	$(1.5 \pm 0.5) \times 10^{-4}$	S=1.4		1218
$\psi(3770)\,K+, \psi \to D^+D^-$	$(9.4 \pm 3.5) \times 10^{-5}$			1218
$\psi(3770)\,K^+$, $\psi \to p\overline{p}$	$< 2 \times 10^{-7}$	CL=95%		–
$\psi(4040)\,K^+$	$< 1.3 \times 10^{-4}$	CL=90%		1003
$\psi(4160)\,K^+$	$(5.1 \pm 2.7) \times 10^{-4}$			868
$\psi(4160)\,K^+$, $\psi \to \overline{D}^0 D^0$	$(8 \pm 5) \times 10^{-5}$			–
$\chi_{c0}\,\pi^+$, $\chi_{c0} \to \pi^+\pi^-$	$< 1 \times 10^{-7}$	CL=90%		1531
$\chi_{c0}\,K^+$	$(1.49\ {}^{+0.15}_{-0.14}) \times 10^{-4}$			1478
$\chi_{c0}\,K^*(892)^+$	$< 2.1 \times 10^{-4}$	CL=90%		1341
$\chi_{c1}(1P)\,\pi^+$	$(2.2 \pm 0.5) \times 10^{-5}$			1468
$\chi_{c1}(1P)\,K^+$	$(4.84 \pm 0.23) \times 10^{-4}$			1412
$\chi_{c1}(1P)\,K^*(892)^+$	$(3.0 \pm 0.6) \times 10^{-4}$	S=1.1		1265
$\chi_{c1}(1P)\,K^0\pi^+$	$(5.8 \pm 0.4) \times 10^{-4}$			1370
$\chi_{c1}(1P)\,K^+\pi^0$	$(3.29 \pm 0.35) \times 10^{-4}$			1373
$\chi_{c1}(1P)\,K^+\pi^+\pi^-$	$(3.74 \pm 0.30) \times 10^{-4}$			1319
$\chi_{c1}(2P)\,K^+$, $\chi_{c1}(2P) \to \pi^+\pi^-\chi_{c1}(1P)$	$< 1.1 \times 10^{-5}$	CL=90%		–

$\chi_{c2} K^+$	$(1.1 \pm 0.4) \times 10^{-5}$		1379
$\chi_{c2} K^*(892)^+$	$< 1.2 \times 10^{-4}$	CL=90%	1228
$\chi_{c2} K^0 \pi^+$	$(1.16 \pm 0.25) \times 10^{-4}$		1336
$\chi_{c2} K^+ \pi^0$	$< 6.2 \times 10^{-5}$	CL=90%	1339
$\chi_{c2} K^+ \pi^+ \pi^-$	$(1.34 \pm 0.19) \times 10^{-4}$		1284
$\chi_{c2}(3930)\pi^+,\ \chi_{c2} \rightarrow \pi^+\pi^-$	$< 1 \times 10^{-7}$	CL=90%	1437
$h_c(1P) K^+$	$< 3.8 \times 10^{-5}$	CL=90%	1401
$h_c(1P) K^+,\ h_c \rightarrow p\overline{p}$	$< 6.4 \times 10^{-8}$	CL=95%	–

K or K^* modes

$K^0 \pi^+$	$(2.37 \pm 0.08) \times 10^{-5}$		2614
$K^+ \pi^0$	$(1.29 \pm 0.05) \times 10^{-5}$		2615
$\eta' K^+$	$(7.06 \pm 0.25) \times 10^{-5}$		2528
$\eta' K^*(892)^+$	$(4.8 {}^{+1.8}_{-1.6}) \times 10^{-6}$		2472
$\eta' K_0^*(1430)^+$	$(5.2 \pm 2.1) \times 10^{-6}$		–
$\eta' K_2^*(1430)^+$	$(2.8 \pm 0.5) \times 10^{-5}$		2346
ηK^+	$(2.4 \pm 0.4) \times 10^{-6}$	S=1.7	2588
$\eta K^*(892)^+$	$(1.93 \pm 0.16) \times 10^{-5}$		2534
$\eta K_0^*(1430)^+$	$(1.8 \pm 0.4) \times 10^{-5}$		–
$\eta K_2^*(1430)^+$	$(9.1 \pm 3.0) \times 10^{-6}$		2414
$\eta(1295) K^+ \times$ B($\eta(1295) \rightarrow \eta\pi\pi$)	$(2.9 {}^{+0.8}_{-0.7}) \times 10^{-6}$		2455
$\eta(1405) K^+ \times$ B($\eta(1405) \rightarrow \eta\pi\pi$)	$< 1.3 \times 10^{-6}$	CL=90%	2425
$\eta(1405) K^+ \times$ B($\eta(1405) \rightarrow K^* K$)	$< 1.2 \times 10^{-6}$	CL=90%	2425
$\eta(1475) K^+ \times$ B($\eta(1475) \rightarrow K^* K$)	$(1.38 {}^{+0.21}_{-0.18}) \times 10^{-5}$		2406
$f_1(1285) K^+$	$< 2.0 \times 10^{-6}$	CL=90%	2458
$f_1(1420) K^+ \times$ B($f_1(1420) \rightarrow \eta\pi\pi$)	$< 2.9 \times 10^{-6}$	CL=90%	2420
$f_1(1420) K^+ \times$ B($f_1(1420) \rightarrow K^* K$)	$< 4.1 \times 10^{-6}$	CL=90%	2420
$\phi(1680) K^+ \times$ B($\phi(1680) \rightarrow K^* K$)	$< 3.4 \times 10^{-6}$	CL=90%	2344
$f_0(1500) K^+$	$(3.7 \pm 2.2) \times 10^{-6}$		2398
ωK^+	$(6.5 \pm 0.4) \times 10^{-6}$		2558
$\omega K^*(892)^+$	$< 7.4 \times 10^{-6}$	CL=90%	2503
$\omega (K\pi)_0^{*+}$	$(2.8 \pm 0.4) \times 10^{-5}$		–
$\omega K_0^*(1430)^+$	$(2.4 \pm 0.5) \times 10^{-5}$		–
$\omega K_2^*(1430)^+$	$(2.1 \pm 0.4) \times 10^{-5}$		2380
$a_0(980)^+ K^0 \times$B($a_0(980)^+ \rightarrow \eta\pi^+$)	$< 3.9 \times 10^{-6}$	CL=90%	–
$a_0(980)^0 K^+ \times$B($a_0(980)^0 \rightarrow \eta\pi^0$)	$< 2.5 \times 10^{-6}$	CL=90%	–
$K^*(892)^0 \pi^+$	$(1.01 \pm 0.08) \times 10^{-5}$		2562
$K^*(892)^+ \pi^0$	$(6.8 \pm 0.9) \times 10^{-6}$		2563
$K^+ \pi^- \pi^+$	$(5.10 \pm 0.29) \times 10^{-5}$		2609
$K^+ \pi^- \pi^+$ nonresonant	$(1.63 {}^{+0.21}_{-0.15}) \times 10^{-5}$		2609
$\omega(782) K^+$	$(6 \pm 9) \times 10^{-6}$		2558
$K^+ f_0(980) \times$ B($f_0(980) \rightarrow \pi^+\pi^-$)	$(9.4 {}^{+1.0}_{-1.2}) \times 10^{-6}$		2522
$f_2(1270)^0 K^+$	$(1.07 \pm 0.27) \times 10^{-6}$		–

$f_0(1370)^0 K^+ \times$ B$(f_0(1370)^0 \to \pi^+\pi^-)$	$< 1.07 \times 10^{-5}$	CL=90%	–
$\rho^0(1450) K^+ \times$ B$(\rho^0(1450) \to \pi^+\pi^-)$	$< 1.17 \times 10^{-5}$	CL=90%	–
$f'_2(1525) K^+ \times$ B$(f'_2(1525) \to \pi^+\pi^-)$	$< 3.4 \times 10^{-6}$	CL=90%	2392
$K^+\rho^0$	$(3.7 \pm 0.5) \times 10^{-6}$		2559
$K_0^*(1430)^0 \pi^+$	$(3.9 {}^{+0.6}_{-0.5}) \times 10^{-5}$	S=1.4	2445
$K_0^*(1430)^+ \pi^0$	$(1.19 {}^{+0.20}_{-0.23}) \times 10^{-5}$		–
$K_2^*(1430)^0 \pi^+$	$(5.6 {}^{+2.2}_{-1.5}) \times 10^{-6}$		2445
$K^*(1410)^0 \pi^+$	$< 4.5 \times 10^{-5}$	CL=90%	2446
$K^*(1680)^0 \pi^+$	$< 1.2 \times 10^{-5}$	CL=90%	2358
$K^+\pi^0\pi^0$	$(1.62 \pm 0.19) \times 10^{-5}$		2610
$f_0(980) K^+ \times$ B$(f_0 \to \pi^0\pi^0)$	$(2.8 \pm 0.8) \times 10^{-6}$		2522
$K^-\pi^+\pi^+$	$< 4.6 \times 10^{-8}$	CL=90%	2609
$K^-\pi^+\pi^+$ nonresonant	$< 5.6 \times 10^{-5}$	CL=90%	2609
$K_1(1270)^0 \pi^+$	$< 4.0 \times 10^{-5}$	CL=90%	2484
$K_1(1400)^0 \pi^+$	$< 3.9 \times 10^{-5}$	CL=90%	2451
$K^0\pi^+\pi^0$	$< 6.6 \times 10^{-5}$	CL=90%	2609
$K^0\rho^+$	$(7.3 {}^{+1.0}_{-1.2}) \times 10^{-6}$		2558
$K^*(892)^+\pi^+\pi^-$	$(7.5 \pm 1.0) \times 10^{-5}$		2557
$K^*(892)^+\rho^0$	$(4.6 \pm 1.1) \times 10^{-6}$		2504
$K^*(892)^+ f_0(980)$	$(4.2 \pm 0.7) \times 10^{-6}$		2466
$a_1^+ K^0$	$(3.5 \pm 0.7) \times 10^{-5}$		–
$b_1^+ K^0 \times$ B$(b_1^+ \to \omega\pi^+)$	$(9.6 \pm 1.9) \times 10^{-6}$		–
$K^*(892)^0 \rho^+$	$(9.2 \pm 1.5) \times 10^{-6}$		2504
$K_1(1400)^+ \rho^0$	$< 7.8 \times 10^{-4}$	CL=90%	2388
$K_2^*(1430)^+ \rho^0$	$< 1.5 \times 10^{-3}$	CL=90%	2381
$b_1^0 K^+ \times$ B$(b_1^0 \to \omega\pi^0)$	$(9.1 \pm 2.0) \times 10^{-6}$		–
$b_1^+ K^{*0} \times$ B$(b_1^+ \to \omega\pi^+)$	$< 5.9 \times 10^{-6}$	CL=90%	–
$b_1^0 K^{*+} \times$ B$(b_1^0 \to \omega\pi^0)$	$< 6.7 \times 10^{-6}$	CL=90%	–
$K^+\overline{K}^0$	$(1.31 \pm 0.17) \times 10^{-6}$	S=1.2	2593
$\overline{K}^0 K^+\pi^0$	$< 2.4 \times 10^{-5}$	CL=90%	2578
$K^+ K_S^0 K_S^0$	$(1.08 \pm 0.06) \times 10^{-5}$		2521
$f_0(980) K^+$, $f_0 \to K_S^0 K_S^0$	$(1.47 \pm 0.33) \times 10^{-5}$		–
$f_0(1710) K^+$, $f_0 \to K_S^0 K_S^0$	$(4.8 {}^{+4.0}_{-2.6}) \times 10^{-7}$		–
$K^+ K_S^0 K_S^0$ nonresonant	$(2.0 \pm 0.4) \times 10^{-5}$		2521
$K_S^0 K_S^0 \pi^+$	$< 5.1 \times 10^{-7}$	CL=90%	2577
$K^+K^-\pi^+$	$(5.2 \pm 0.4) \times 10^{-6}$		2578
$K^+K^-\pi^+$ nonresonant	$< 7.5 \times 10^{-5}$	CL=90%	2578
$K^+\overline{K}^*(892)^0$	$< 1.1 \times 10^{-6}$	CL=90%	2540
$K^+\overline{K}_0^*(1430)^0$	$< 2.2 \times 10^{-6}$	CL=90%	2421
$K^+K^+\pi^-$	$< 1.1 \times 10^{-8}$	CL=90%	2578
$K^+K^+\pi^-$ nonresonant	$< 8.79 \times 10^{-5}$	CL=90%	2578
$f'_2(1525) K^+$	$(1.8 \pm 0.5) \times 10^{-6}$	S=1.1	2392
$K^{*+}\pi^+K^-$	$< 1.18 \times 10^{-5}$	CL=90%	2524
$K^*(892)^+ K^*(892)^0$	$(9.1 \pm 2.9) \times 10^{-7}$		2484
$K^{*+}K^+\pi^-$	$< 6.1 \times 10^{-6}$	CL=90%	2524
$K^+K^-K^+$	$(3.40 \pm 0.14) \times 10^{-5}$	S=1.4	2523
$K^+\phi$	$(8.8 {}^{+0.7}_{-0.6}) \times 10^{-6}$	S=1.1	2516

$f_0(980)K^+ \times$ B($f_0(980) \to K^+K^-$)	$(9.4 \pm 3.2) \times 10^{-6}$			2522
$a_2(1320)K^+ \times$ B($a_2(1320) \to K^+K^-$)	$< 1.1 \times 10^{-6}$	CL=90%		2449
$X_0(1550)K^+ \times$ B($X_0(1550) \to K^+K^-$)	$(4.3 \pm 0.7) \times 10^{-6}$			–
$\phi(1680)K^+ \times$ B($\phi(1680) \to K^+K^-$)	$< 8 \times 10^{-7}$	CL=90%		2344
$f_0(1710)K^+ \times$ B($f_0(1710) \to K^+K^-$)	$(1.1 \pm 0.6) \times 10^{-6}$			2330
$K^+K^-K^+$ nonresonant	$(2.38 {}^{+0.28}_{-0.50}) \times 10^{-5}$			2523
$K^*(892)^+K^+K^-$	$(3.6 \pm 0.5) \times 10^{-5}$			2466
$K^*(892)^+\phi$	$(10.0 \pm 2.0) \times 10^{-6}$	S=1.7		2460
$\phi(K\pi)^{*+}_0$	$(8.3 \pm 1.6) \times 10^{-6}$			–
$\phi K_1(1270)^+$	$(6.1 \pm 1.9) \times 10^{-6}$			2375
$\phi K_1(1400)^+$	$< 3.2 \times 10^{-6}$	CL=90%		2339
$\phi K^*(1410)^+$	$< 4.3 \times 10^{-6}$	CL=90%		–
$\phi K^*_0(1430)^+$	$(7.0 \pm 1.6) \times 10^{-6}$			–
$\phi K^*_2(1430)^+$	$(8.4 \pm 2.1) \times 10^{-6}$			2333
$\phi K^*_2(1770)^+$	$< 1.50 \times 10^{-5}$	CL=90%		–
$\phi K^*_2(1820)^+$	$< 1.63 \times 10^{-5}$	CL=90%		–
$a_1^+ K^{*0}$	$< 3.6 \times 10^{-6}$	CL=90%		–
$K^+\phi\phi$	$(5.0 \pm 1.2) \times 10^{-6}$	S=2.3		2306
$\eta'\eta' K^+$	$< 2.5 \times 10^{-5}$	CL=90%		2338
$\omega\phi K^+$	$< 1.9 \times 10^{-6}$	CL=90%		2374
$X(1812)K^+ \times$ B($X \to \omega\phi$)	$< 3.2 \times 10^{-7}$	CL=90%		–
$K^*(892)^+\gamma$	$(3.92 \pm 0.22) \times 10^{-5}$	S=1.7		2564
$K_1(1270)^+\gamma$	$(4.4 {}^{+0.7}_{-0.6}) \times 10^{-5}$			2486
$\eta K^+\gamma$	$(7.9 \pm 0.9) \times 10^{-6}$			2588
$\eta' K^+\gamma$	$(2.9 {}^{+1.0}_{-0.9}) \times 10^{-6}$			2528
$\phi K^+\gamma$	$(2.7 \pm 0.4) \times 10^{-6}$	S=1.2		2516
$K^+\pi^-\pi^+\gamma$	$(2.58 \pm 0.15) \times 10^{-5}$	S=1.3		2609
$K^*(892)^0\pi^+\gamma$	$(2.33 \pm 0.12) \times 10^{-5}$			2562
$K^+\rho^0\gamma$	$(8.2 \pm 0.9) \times 10^{-6}$			2559
$(K^+\pi^-)_{\rm NR}\pi^+\gamma$	$(9.9 {}^{+1.7}_{-2.0}) \times 10^{-6}$			2609
$K^0\pi^+\pi^0\gamma$	$(4.6 \pm 0.5) \times 10^{-5}$			2609
$K_1(1400)^+\gamma$	$(10 {}^{+5}_{-4}) \times 10^{-6}$			2453
$K^*(1410)^+\gamma$	$(2.7 {}^{+0.8}_{-0.6}) \times 10^{-5}$			–
$K^*_0(1430)^0\pi^+\gamma$	$(1.32 {}^{+0.26}_{-0.32}) \times 10^{-6}$			2445
$K^*_2(1430)^+\gamma$	$(1.4 \pm 0.4) \times 10^{-5}$			2447
$K^*(1680)^+\gamma$	$(6.7 {}^{+1.7}_{-1.4}) \times 10^{-5}$			2360
$K^*_3(1780)^+\gamma$	$< 3.9 \times 10^{-5}$	CL=90%		2341
$K^*_4(2045)^+\gamma$	$< 9.9 \times 10^{-3}$	CL=90%		2244
Light unflavored meson modes				
$\rho^+\gamma$	$(9.8 \pm 2.5) \times 10^{-7}$			2583
$\pi^+\pi^0$	$(5.5 \pm 0.4) \times 10^{-6}$	S=1.2		2636
$\pi^+\pi^+\pi^-$	$(1.52 \pm 0.14) \times 10^{-5}$			2630
$\rho^0\pi^+$	$(8.3 \pm 1.2) \times 10^{-6}$			2581
$\pi^+ f_0(980)$, $f_0 \to \pi^+\pi^-$	$< 1.5 \times 10^{-6}$	CL=90%		2545

$\pi^+ f_2(1270)$	$(1.6\ ^{+0.7}_{-0.4})\times 10^{-6}$		2484
$\rho(1450)^0\pi^+,\ \rho^0 \to \pi^+\pi^-$	$(1.4\ ^{+0.6}_{-0.9})\times 10^{-6}$		2434
$f_0(1370)\pi^+,\ f_0 \to \pi^+\pi^-$	$< 4.0 \times 10^{-6}$	CL=90%	2460
$f_0(500)\pi^+,\ f_0 \to \pi^+\pi^-$	$< 4.1 \times 10^{-6}$	CL=90%	–
$\pi^+\pi^-\pi^+$ nonresonant	$(5.3\ ^{+1.5}_{-1.1})\times 10^{-6}$		2630
$\pi^+\pi^0\pi^0$	$< 8.9 \times 10^{-4}$	CL=90%	2631
$\rho^+\pi^0$	$(1.09 \pm 0.14)\times 10^{-5}$		2581
$\pi^+\pi^-\pi^+\pi^0$	$< 4.0 \times 10^{-3}$	CL=90%	2622
$\rho^+\rho^0$	$(2.40 \pm 0.19)\times 10^{-5}$		2523
$\rho^+ f_0(980),\ f_0 \to \pi^+\pi^-$	$< 2.0 \times 10^{-6}$	CL=90%	2486
$a_1(1260)^+\pi^0$	$(2.6 \pm 0.7)\times 10^{-5}$		2494
$a_1(1260)^0\pi^+$	$(2.0 \pm 0.6)\times 10^{-5}$		2494
$\omega\pi^+$	$(6.9 \pm 0.5)\times 10^{-6}$		2580
$\omega\rho^+$	$(1.59 \pm 0.21)\times 10^{-5}$		2522
$\eta\pi^+$	$(4.02 \pm 0.27)\times 10^{-6}$		2609
$\eta\rho^+$	$(7.0 \pm 2.9)\times 10^{-6}$	S=2.8	2553
$\eta'\pi^+$	$(2.7 \pm 0.9)\times 10^{-6}$	S=1.9	2551
$\eta'\rho^+$	$(9.7 \pm 2.2)\times 10^{-6}$		2492
$\phi\pi^+$	$< 1.5 \times 10^{-7}$	CL=90%	2539
$\phi\rho^+$	$< 3.0 \times 10^{-6}$	CL=90%	2480
$a_0(980)^0\pi^+,\ a_0^0 \to \eta\pi^0$	$< 5.8 \times 10^{-6}$	CL=90%	–
$a_0(980)^+\pi^0,\ a_0^+ \to \eta\pi^+$	$< 1.4 \times 10^{-6}$	CL=90%	–
$\pi^+\pi^+\pi^+\pi^-\pi^-$	$< 8.6 \times 10^{-4}$	CL=90%	2608
$\rho^0 a_1(1260)^+$	$< 6.2 \times 10^{-4}$	CL=90%	2433
$\rho^0 a_2(1320)^+$	$< 7.2 \times 10^{-4}$	CL=90%	2410
$b_1^0\pi^+,\ b_1^0 \to \omega\pi^0$	$(6.7 \pm 2.0)\times 10^{-6}$		–
$b_1^+\pi^0,\ b_1^+ \to \omega\pi^+$	$< 3.3 \times 10^{-6}$	CL=90%	–
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^0$	$< 6.3 \times 10^{-3}$	CL=90%	2592
$b_1^+\rho^0,\ b_1^+ \to \omega\pi^+$	$< 5.2 \times 10^{-6}$	CL=90%	–
$a_1(1260)^+ a_1(1260)^0$	< 1.3 %	CL=90%	2336
$b_1^0\rho^+,\ b_1^0 \to \omega\pi^0$	$< 3.3 \times 10^{-6}$	CL=90%	–

Charged particle ($h^\pm$) modes

$h^\pm = K^\pm$ or $\pi^\pm$

$h^+\pi^0$	$(1.6\ ^{+0.7}_{-0.6})\times 10^{-5}$		2636
ωh^+	$(1.38\ ^{+0.27}_{-0.24})\times 10^{-5}$		2580
h^+X^0 (Familon)	$< 4.9 \times 10^{-5}$	CL=90%	–
$K^+X^0,\ X^0 \to \mu^+\mu^-$	$< 1 \times 10^{-7}$	CL=95%	–

Baryon modes

$p\overline{p}\pi^+$	$(1.62 \pm 0.20)\times 10^{-6}$		2439
$p\overline{p}\pi^+$ nonresonant	$< 5.3 \times 10^{-5}$	CL=90%	2439
$p\overline{p}K^+$	$(5.9 \pm 0.5)\times 10^{-6}$	S=1.5	2348
$\Theta(1710)^{++}\overline{p},\ \Theta^{++} \to pK^+$ [zzz]	$< 9.1 \times 10^{-8}$	CL=90%	–
$f_J(2220)K^+,\ f_J \to p\overline{p}$ [zzz]	$< 4.1 \times 10^{-7}$	CL=90%	2135
$p\overline{\Lambda}(1520)$	$(3.1 \pm 0.6)\times 10^{-7}$		2322
$p\overline{p}K^+$ nonresonant	$< 8.9 \times 10^{-5}$	CL=90%	2348
$p\overline{p}K^*(892)^+$	$(3.6\ ^{+0.8}_{-0.7})\times 10^{-6}$		2215
$f_J(2220)K^{*+},\ f_J \to p\overline{p}$	$< 7.7 \times 10^{-7}$	CL=90%	2059
$p\overline{\Lambda}$	$(2.4\ ^{+1.0}_{-0.9})\times 10^{-7}$		2430

$p\overline{\Lambda}\gamma$			$(2.4 \,{}^{+0.5}_{-0.4}) \times 10^{-6}$		2430
$p\overline{\Lambda}\pi^0$			$(3.0 \,{}^{+0.7}_{-0.6}) \times 10^{-6}$		2402
$p\overline{\Sigma}(1385)^0$			$< 4.7 \times 10^{-7}$	CL=90%	2362
$\Delta^+\overline{\Lambda}$			$< 8.2 \times 10^{-7}$	CL=90%	–
$p\overline{\Sigma}\gamma$			$< 4.6 \times 10^{-6}$	CL=90%	2413
$p\overline{\Lambda}\pi^+\pi^-$			$(5.9 \pm 1.1) \times 10^{-6}$		2367
$p\overline{\Lambda}\rho^0$			$(4.8 \pm 0.9) \times 10^{-6}$		2214
$p\overline{\Lambda}f_2(1270)$			$(2.0 \pm 0.8) \times 10^{-6}$		2026
$\Lambda\overline{\Lambda}\pi^+$			$< 9.4 \times 10^{-7}$	CL=90%	2358
$\Lambda\overline{\Lambda}K^+$			$(3.4 \pm 0.6) \times 10^{-6}$		2251
$\Lambda\overline{\Lambda}K^{*+}$			$(2.2 \,{}^{+1.2}_{-0.9}) \times 10^{-6}$		2098
$\overline{\Delta}^0 p$			$< 1.38 \times 10^{-6}$	CL=90%	2403
$\Delta^{++}\overline{p}$			$< 1.4 \times 10^{-7}$	CL=90%	2403
$D^+ p\overline{p}$			$< 1.5 \times 10^{-5}$	CL=90%	1860
$D^*(2010)^+ p\overline{p}$			$< 1.5 \times 10^{-5}$	CL=90%	1786
$\overline{D}^0 p\overline{p}\pi^+$			$(3.72 \pm 0.27) \times 10^{-4}$		1789
$\overline{D}^{*0} p\overline{p}\pi^+$			$(3.73 \pm 0.32) \times 10^{-4}$		1709
$D^- p\overline{p}\pi^+\pi^-$			$(1.66 \pm 0.30) \times 10^{-4}$		1705
$D^{*-} p\overline{p}\pi^+\pi^-$			$(1.86 \pm 0.25) \times 10^{-4}$		1621
$p\overline{\Lambda}^0\overline{D}^0$			$(1.43 \pm 0.32) \times 10^{-5}$		–
$p\overline{\Lambda}^0\overline{D}^*(2007)^0$			$< 5 \times 10^{-5}$	CL=90%	–
$\overline{\Lambda}_c^- p\pi^+$			$(2.3 \pm 0.4) \times 10^{-4}$	S=2.2	1980
$\overline{\Lambda}_c^- \Delta(1232)^{++}$			$< 1.9 \times 10^{-5}$	CL=90%	1928
$\overline{\Lambda}_c^- \Delta_X(1600)^{++}$			$(4.7 \pm 1.0) \times 10^{-5}$		–
$\overline{\Lambda}_c^- \Delta_X(2420)^{++}$			$(3.8 \pm 0.9) \times 10^{-5}$		–
$(\overline{\Lambda}_c^- p)_s\pi^+$		[aaaa]	$(3.1 \pm 0.7) \times 10^{-5}$		–
$\overline{\Sigma}_c(2520)^0 p$			$< 3 \times 10^{-6}$	CL=90%	1904
$\overline{\Sigma}_c(2800)^0 p$			$(2.7 \pm 0.9) \times 10^{-5}$		–
$\overline{\Lambda}_c^- p\pi^+\pi^0$			$(1.8 \pm 0.6) \times 10^{-3}$		1935
$\overline{\Lambda}_c^- p\pi^+\pi^+\pi^-$			$(2.2 \pm 0.7) \times 10^{-3}$		1880
$\overline{\Lambda}_c^- p\pi^+\pi^+\pi^-\pi^0$			< 1.34 %	CL=90%	1823
$\Lambda_c^+\Lambda_c^- K^+$			$(7.0 \pm 2.2) \times 10^{-4}$		–
$\overline{\Sigma}_c(2455)^0 p$			$(3.0 \pm 0.7) \times 10^{-5}$		1938
$\overline{\Sigma}_c(2455)^0 p\pi^0$			$(3.5 \pm 1.1) \times 10^{-4}$		1896
$\overline{\Sigma}_c(2455)^0 p\pi^-\pi^+$			$(3.5 \pm 1.1) \times 10^{-4}$		1845
$\overline{\Sigma}_c(2455)^{--} p\pi^+\pi^+$			$(2.39 \pm 0.20) \times 10^{-4}$		1845
$\overline{\Lambda}_c(2593)^- / \overline{\Lambda}_c(2625)^- p\pi^+$			$< 1.9 \times 10^{-4}$	CL=90%	–
$\Xi_c^0\Lambda_c^+,\ \Xi_c^0 \to \Xi^+\pi^-$			$(2.4 \pm 0.9) \times 10^{-5}$	S=1.4	1144
$\Xi_c^0\Lambda_c^+,\ \Xi_c^0 \to \Lambda K^+\pi^-$			$(2.1 \pm 0.9) \times 10^{-5}$	S=1.5	1144
Lepton Family number (*LF*) or Lepton number (*L*) or Baryon number (*B*) violating modes, or/and $\Delta B = 1$ weak neutral current (*B1*) modes					
$\pi^+\ell^+\ell^-$	*B1*		$< 4.9 \times 10^{-8}$	CL=90%	2638
$\pi^+ e^+ e^-$	*B1*		$< 8.0 \times 10^{-8}$	CL=90%	2638
$\pi^+\mu^+\mu^-$	*B1*		$(1.76 \pm 0.23) \times 10^{-8}$		2634
$\pi^+\nu\overline{\nu}$	*B1*		$< 1.4 \times 10^{-5}$	CL=90%	2638
$K^+\ell^+\ell^-$	*B1*	[sss]	$(4.51 \pm 0.23) \times 10^{-7}$	S=1.1	2617
$K^+ e^+ e^-$	*B1*		$(5.5 \pm 0.7) \times 10^{-7}$		2617
$K^+\mu^+\mu^-$	*B1*		$(4.41 \pm 0.23) \times 10^{-7}$	S=1.2	2612
$K^+\mu^+\mu^-$ nonresonant	*B1*		$(4.37 \pm 0.27) \times 10^{-7}$		2612
$K^+\tau^+\tau^-$	*B1*		$< 2.25 \times 10^{-3}$	CL=90%	1687
$K^+\overline{\nu}\nu$	*B1*		$< 1.6 \times 10^{-5}$	CL=90%	2617

$\rho^+ \nu \overline{\nu}$	B1		< 3.0	$\times 10^{-5}$	CL=90%	2583
$K^*(892)^+ \ell^+ \ell^-$	B1	[sss]	$(1.01 \pm 0.11) \times 10^{-6}$		S=1.1	2564
$\quad K^*(892)^+ e^+ e^-$	B1		$(1.55 {+0.40 \atop -0.31}) \times 10^{-6}$			2564
$\quad K^*(892)^+ \mu^+ \mu^-$	B1		$(9.6 \pm 1.0) \times 10^{-7}$			2560
$K^*(892)^+ \nu \overline{\nu}$	B1		< 4.0	$\times 10^{-5}$	CL=90%	2564
$K^+ \pi^+ \pi^- \mu^+ \mu^-$	B1		$(4.3 \pm 0.4) \times 10^{-7}$			2593
$\phi K^+ \mu^+ \mu^-$	B1		$(7.9 {+2.1 \atop -1.7}) \times 10^{-8}$			2490
$\pi^+ e^+ \mu^-$	LF		< 6.4	$\times 10^{-3}$	CL=90%	2637
$\pi^+ e^- \mu^+$	LF		< 6.4	$\times 10^{-3}$	CL=90%	2637
$\pi^+ e^\pm \mu^\mp$	LF		< 1.7	$\times 10^{-7}$	CL=90%	2637
$\pi^+ e^+ \tau^-$	LF		< 7.4	$\times 10^{-5}$	CL=90%	2338
$\pi^+ e^- \tau^+$	LF		< 2.0	$\times 10^{-5}$	CL=90%	2338
$\pi^+ e^\pm \tau^\mp$	LF		< 7.5	$\times 10^{-5}$	CL=90%	2338
$\pi^+ \mu^+ \tau^-$	LF		< 6.2	$\times 10^{-5}$	CL=90%	2333
$\pi^+ \mu^- \tau^+$	LF		< 4.5	$\times 10^{-5}$	CL=90%	2333
$\pi^+ \mu^\pm \tau^\mp$	LF		< 7.2	$\times 10^{-5}$	CL=90%	2333
$K^+ e^+ \mu^-$	LF		< 9.1	$\times 10^{-8}$	CL=90%	2615
$K^+ e^- \mu^+$	LF		< 1.3	$\times 10^{-7}$	CL=90%	2615
$K^+ e^\pm \mu^\mp$	LF		< 9.1	$\times 10^{-8}$	CL=90%	2615
$K^+ e^+ \tau^-$	LF		< 4.3	$\times 10^{-5}$	CL=90%	2312
$K^+ e^- \tau^+$	LF		< 1.5	$\times 10^{-5}$	CL=90%	2312
$K^+ e^\pm \tau^\mp$	LF		< 3.0	$\times 10^{-5}$	CL=90%	2312
$K^+ \mu^+ \tau^-$	LF		< 4.5	$\times 10^{-5}$	CL=90%	2298
$K^+ \mu^- \tau^+$	LF		< 2.8	$\times 10^{-5}$	CL=90%	2298
$K^+ \mu^\pm \tau^\mp$	LF		< 4.8	$\times 10^{-5}$	CL=90%	2298
$K^*(892)^+ e^+ \mu^-$	LF		< 1.3	$\times 10^{-6}$	CL=90%	2563
$K^*(892)^+ e^- \mu^+$	LF		< 9.9	$\times 10^{-7}$	CL=90%	2563
$K^*(892)^+ e^\pm \mu^\mp$	LF		< 1.4	$\times 10^{-6}$	CL=90%	2563
$\pi^- e^+ e^+$	L		< 2.3	$\times 10^{-8}$	CL=90%	2638
$\pi^- \mu^+ \mu^+$	L		< 4.0	$\times 10^{-9}$	CL=95%	2634
$\pi^- e^+ \mu^+$	L		< 1.5	$\times 10^{-7}$	CL=90%	2637
$\rho^- e^+ e^+$	L		< 1.7	$\times 10^{-7}$	CL=90%	2583
$\rho^- \mu^+ \mu^+$	L		< 4.2	$\times 10^{-7}$	CL=90%	2578
$\rho^- e^+ \mu^+$	L		< 4.7	$\times 10^{-7}$	CL=90%	2582
$K^- e^+ e^+$	L		< 3.0	$\times 10^{-8}$	CL=90%	2617
$K^- \mu^+ \mu^+$	L		< 4.1	$\times 10^{-8}$	CL=90%	2612
$K^- e^+ \mu^+$	L		< 1.6	$\times 10^{-7}$	CL=90%	2615
$K^*(892)^- e^+ e^+$	L		< 4.0	$\times 10^{-7}$	CL=90%	2564
$K^*(892)^- \mu^+ \mu^+$	L		< 5.9	$\times 10^{-7}$	CL=90%	2560
$K^*(892)^- e^+ \mu^+$	L		< 3.0	$\times 10^{-7}$	CL=90%	2563
$D^- e^+ e^+$	L		< 2.6	$\times 10^{-6}$	CL=90%	2309
$D^- e^+ \mu^+$	L		< 1.8	$\times 10^{-6}$	CL=90%	2307
$D^- \mu^+ \mu^+$	L		< 6.9	$\times 10^{-7}$	CL=95%	2303
$D^{*-} \mu^+ \mu^+$	L		< 2.4	$\times 10^{-6}$	CL=95%	2251
$D_s^- \mu^+ \mu^+$	L		< 5.8	$\times 10^{-7}$	CL=95%	2267
$\overline{D}^0 \pi^- \mu^+ \mu^+$	L		< 1.5	$\times 10^{-6}$	CL=95%	2295
$\Lambda^0 \mu^+$	L,B		< 6	$\times 10^{-8}$	CL=90%	–
$\Lambda^0 e^+$	L,B		< 3.2	$\times 10^{-8}$	CL=90%	–
$\overline{\Lambda}^0 \mu^+$	L,B		< 6	$\times 10^{-8}$	CL=90%	–
$\overline{\Lambda}^0 e^+$	L,B		< 8	$\times 10^{-8}$	CL=90%	–

See Particle Listings for 15 decay modes that have been seen / not seen.

B^0

$I(J^P) = \frac{1}{2}(0^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B^0} = 5279.63 \pm 0.15$ MeV (S = 1.1)
$m_{B^0} - m_{B^\pm} = 0.31 \pm 0.06$ MeV
Mean life $\tau_{B^0} = (1.520 \pm 0.004) \times 10^{-12}$ s
$c\tau = 455.7\ \mu$m
$\tau_{B^+}/\tau_{B^0} = 1.076 \pm 0.004$ (direct measurements)

B^0-$\overline{B}^0$ mixing parameters

$\chi_d = 0.1860 \pm 0.0011$
$\Delta m_{B^0} = m_{B^0_H} - m_{B^0_L} = (0.5064 \pm 0.0019) \times 10^{12}\ \hbar\ s^{-1}$
$= (3.333 \pm 0.013) \times 10^{-10}$ MeV
$x_d = \Delta m_{B^0}/\Gamma_{B^0} = 0.770 \pm 0.004$
$\mathrm{Re}(\lambda_{CP} / |\lambda_{CP}|)\ \mathrm{Re}(z) = 0.047 \pm 0.022$
$\Delta\Gamma\ \mathrm{Re}(z) = -0.007 \pm 0.004$
$\mathrm{Re}(z) = (-4 \pm 4) \times 10^{-2}$ (S = 1.4)
$\mathrm{Im}(z) = (-0.8 \pm 0.4) \times 10^{-2}$

CP violation parameters

$\mathrm{Re}(\epsilon_{B^0})/(1+|\epsilon_{B^0}|^2) = (-0.5 \pm 0.4) \times 10^{-3}$
$A_{T/CP}(B^0 \leftrightarrow \overline{B}^0) = 0.005 \pm 0.018$
$A_{CP}(B^0 \to D^*(2010)^+ D^-) = 0.037 \pm 0.034$
$A_{CP}(B^0 \to [K^+\pi^-]_D K^*(892)^0) = -0.03 \pm 0.04$
$R_d^+ = \Gamma(B^0 \to [\pi^+ K^-]_D K^{*0}) / \Gamma(B^0 \to [\pi^- K^+]_D K^{*0}) = 0.06 \pm 0.032$
$R_d^- = \Gamma(\overline{B}^0 \to [\pi^- K^+]_D K^{*0}) / \Gamma(\overline{B}^0 \to [\pi^+ K^-]_D K^{*0}) = 0.06 \pm 0.032$
$\boldsymbol{A_{CP}(B^0 \to K^+\pi^-)} = -0.082 \pm 0.006$
$A_{CP}(B^0 \to \eta' K^*(892)^0) = -0.07 \pm 0.18$
$A_{CP}(B^0 \to \eta' K_0^*(1430)^0) = -0.19 \pm 0.17$
$A_{CP}(B^0 \to \eta' K_2^*(1430)^0) = 0.14 \pm 0.18$
$\boldsymbol{A_{CP}(B^0 \to \eta K^*(892)^0)} = 0.19 \pm 0.05$
$A_{CP}(B^0 \to \eta K_0^*(1430)^0) = 0.06 \pm 0.13$
$A_{CP}(B^0 \to \eta K_2^*(1430)^0) = -0.07 \pm 0.19$
$A_{CP}(B^0 \to b_1 K^+) = -0.07 \pm 0.12$
$A_{CP}(B^0 \to \omega K^{*0}) = 0.45 \pm 0.25$
$A_{CP}(B^0 \to \omega (K\pi)_0^{*0}) = -0.07 \pm 0.09$
$A_{CP}(B^0 \to \omega K_2^*(1430)^0) = -0.37 \pm 0.17$
$A_{CP}(B^0 \to K^+\pi^-\pi^0) = (0 \pm 6) \times 10^{-2}$
$A_{CP}(B^0 \to \rho^- K^+) = 0.20 \pm 0.11$
$A_{CP}(B^0 \to \rho(1450)^- K^+) = -0.10 \pm 0.33$
$A_{CP}(B^0 \to \rho(1700)^- K^+) = -0.4 \pm 0.6$
$A_{CP}(B^0 \to K^+\pi^-\pi^0\ \mathrm{nonresonant}) = 0.10 \pm 0.18$
$A_{CP}(B^0 \to K^0\pi^+\pi^-) = -0.01 \pm 0.05$
$\boldsymbol{A_{CP}(B^0 \to K^*(892)^+\pi^-)} = -0.22 \pm 0.06$
$A_{CP}(B^0 \to (K\pi)_0^{*+}\pi^-) = 0.09 \pm 0.07$
$A_{CP}(B^0 \to (K\pi)_0^{*0}\pi^0) = -0.15 \pm 0.11$
$A_{CP}(B^0 \to K^{*0}\pi^0) = -0.15 \pm 0.13$
$A_{CP}(B^0 \to K^*(892)^0\pi^+\pi^-) = 0.07 \pm 0.05$

$A_{CP}(B^0 \to K^*(892)^0 \rho^0) = -0.06 \pm 0.09$
$A_{CP}(B^0 \to K^{*0} f_0(980)) = 0.07 \pm 0.10$
$A_{CP}(B^0 \to K^{*+} \rho^-) = 0.21 \pm 0.15$
$A_{CP}(B^0 \to K^*(892)^0 K^+ K^-) = 0.01 \pm 0.05$
$A_{CP}(B^0 \to a_1^- K^+) = -0.16 \pm 0.12$
$A_{CP}(B^0 \to K^0 \overline{K}^0) = -0.6 \pm 0.7$
$A_{CP}(B^0 \to K^*(892)^0 \phi) = 0.00 \pm 0.04$
$A_{CP}(B^0 \to K^*(892)^0 K^- \pi^+) = 0.2 \pm 0.4$
$A_{CP}(B^0 \to \phi (K\pi)_0^{*0}) = 0.12 \pm 0.08$
$A_{CP}(B^0 \to \phi K_2^*(1430)^0) = -0.11 \pm 0.10$
$A_{CP}(B^0 \to K^*(892)^0 \gamma) = -0.006 \pm 0.011$
$A_{CP}(B^0 \to K_2^*(1430)^0 \gamma) = -0.08 \pm 0.15$
$A_{CP}(B^0 \to \rho^+ \pi^-) = 0.13 \pm 0.06$ (S = 1.1)
$A_{CP}(B^0 \to \rho^- \pi^+) = -0.08 \pm 0.08$
$A_{CP}(B^0 \to a_1(1260)^\pm \pi^\mp) = -0.07 \pm 0.06$
$A_{CP}(B^0 \to b_1^- \pi^+) = -0.05 \pm 0.10$
$A_{CP}(B^0 \to p \overline{p} K^*(892)^0) = 0.05 \pm 0.12$
$A_{CP}(B^0 \to p \overline{\Lambda} \pi^-) = 0.04 \pm 0.07$
$A_{CP}(B^0 \to K^{*0} \ell^+ \ell^-) = -0.05 \pm 0.10$
$A_{CP}(B^0 \to K^{*0} e^+ e^-) = -0.21 \pm 0.19$
$A_{CP}(B^0 \to K^{*0} \mu^+ \mu^-) = -0.034 \pm 0.024$
$C_{D^{*-} D^+} (B^0 \to D^*(2010)^- D^+) = -0.01 \pm 0.11$
$\boldsymbol{S_{D^{*-} D^+} (B^0 \to D^*(2010)^- D^+)} = -0.72 \pm 0.15$
$C_{D^{*+} D^-} (B^0 \to D^*(2010)^+ D^-) = 0.00 \pm 0.13$ (S = 1.3)
$\boldsymbol{S_{D^{*+} D^-} (B^0 \to D^*(2010)^+ D^-)} = -0.73 \pm 0.14$
$C_{D^{*+} D^{*-}} (B^0 \to D^{*+} D^{*-}) = 0.01 \pm 0.09$ (S = 1.6)
$\boldsymbol{S_{D^{*+} D^{*-}} (B^0 \to D^{*+} D^{*-})} = -0.59 \pm 0.14$ (S = 1.8)
$C_+ (B^0 \to D^{*+} D^{*-}) = 0.00 \pm 0.10$ (S = 1.6)
$\boldsymbol{S_+ (B^0 \to D^{*+} D^{*-})} = -0.73 \pm 0.09$
$C_- (B^0 \to D^{*+} D^{*-}) = 0.19 \pm 0.31$
$S_- (B^0 \to D^{*+} D^{*-}) = 0.1 \pm 1.6$ (S = 3.5)
$C (B^0 \to D^*(2010)^+ D^*(2010)^- K_S^0) = 0.01 \pm 0.29$
$S (B^0 \to D^*(2010)^+ D^*(2010)^- K_S^0) = 0.1 \pm 0.4$
$C_{D^+ D^-} (B^0 \to D^+ D^-) = -0.22 \pm 0.24$ (S = 2.5)
$\boldsymbol{S_{D^+ D^-} (B^0 \to D^+ D^-)} = -0.76^{+0.15}_{-0.13}$ (S = 1.2)
$C_{J/\psi(1S) \pi^0} (B^0 \to J/\psi(1S) \pi^0) = -0.13 \pm 0.13$
$\boldsymbol{S_{J/\psi(1S) \pi^0} (B^0 \to J/\psi(1S) \pi^0)} = -0.94 \pm 0.29$ (S = 1.9)
$C(B^0 \to J/\psi(1S) \rho^0) = -0.06 \pm 0.06$
$\boldsymbol{S(B^0 \to J/\psi(1S) \rho^0)} = -0.66^{+0.16}_{-0.12}$
$C_{D^{(*)}_{CP} h^0} (B^0 \to D^{(*)}_{CP} h^0) = -0.02 \pm 0.08$
$\boldsymbol{S_{D^{(*)}_{CP} h^0} (B^0 \to D^{(*)}_{CP} h^0)} = -0.66 \pm 0.12$
$C_{K^0 \pi^0} (B^0 \to K^0 \pi^0) = 0.00 \pm 0.13$ (S = 1.4)
$\boldsymbol{S_{K^0 \pi^0} (B^0 \to K^0 \pi^0)} = 0.58 \pm 0.17$
$C_{\eta'(958) K_S^0} (B^0 \to \eta'(958) K_S^0) = -0.04 \pm 0.20$ (S = 2.5)
$S_{\eta'(958) K_S^0} (B^0 \to \eta'(958) K_S^0) = 0.43 \pm 0.17$ (S = 1.5)
$C_{\eta' K^0} (B^0 \to \eta' K^0) = -0.06 \pm 0.04$
$\boldsymbol{S_{\eta' K^0} (B^0 \to \eta' K^0)} = 0.63 \pm 0.06$

$C_{\omega K^0_S}$ $(B^0 \to \omega K^0_S) = 0.0 \pm 0.4$ (S = 3.0)
$S_{\omega K^0_S}$ $(B^0 \to \omega K^0_S) = 0.70 \pm 0.21$
$C\,(B^0 \to K^0_S \pi^0 \pi^0) = 0.2 \pm 0.5$
$S\,(B^0 \to K^0_S \pi^0 \pi^0) = 0.7 \pm 0.7$
$C_{\rho^0 K^0_S}$ $(B^0 \to \rho^0 K^0_S) = -0.04 \pm 0.20$
$S_{\rho^0 K^0_S}$ $(B^0 \to \rho^0 K^0_S) = 0.50^{+0.17}_{-0.21}$
$C_{f_0 K^0_S}$ $(B^0 \to f_0(980) K^0_S) = 0.29 \pm 0.20$
$\boldsymbol{S_{f_0 K^0_S}}$ **$\boldsymbol{(B^0 \to f_0(980) K^0_S)}$** $= -0.50 \pm 0.16$
$S_{f_2 K^0_S}$ $(B^0 \to f_2(1270) K^0_S) = -0.5 \pm 0.5$
$C_{f_2 K^0_S}$ $(B^0 \to f_2(1270) K^0_S) = 0.3 \pm 0.4$
$S_{f_x K^0_S}$ $(B^0 \to f_x(1300) K^0_S) = -0.2 \pm 0.5$
$C_{f_x K^0_S}$ $(B^0 \to f_x(1300) K^0_S) = 0.13 \pm 0.35$
$S_{K^0 \pi^+ \pi^-}$ $(B^0 \to K^0 \pi^+ \pi^-$ nonresonant$) = -0.01 \pm 0.33$
$C_{K^0 \pi^+ \pi^-}$ $(B^0 \to K^0 \pi^+ \pi^-$ nonresonant$) = 0.01 \pm 0.26$
$C_{K^0_S K^0_S}$ $(B^0 \to K^0_S K^0_S) = 0.0 \pm 0.4$ (S = 1.4)
$S_{K^0_S K^0_S}$ $(B^0 \to K^0_S K^0_S) = -0.8 \pm 0.5$
$C_{K^+ K^- K^0_S}$ $(B^0 \to K^+ K^- K^0_S$ nonresonant$) = 0.06 \pm 0.08$
$\boldsymbol{S_{K^+ K^- K^0_S}}$ **$\boldsymbol{(B^0 \to K^+ K^- K^0_S}$ nonresonant$)$** $= -0.66 \pm 0.11$
$C_{K^+ K^- K^0_S}$ $(B^0 \to K^+ K^- K^0_S$ inclusive$) = 0.01 \pm 0.09$
$\boldsymbol{S_{K^+ K^- K^0_S}}$ **$\boldsymbol{(B^0 \to K^+ K^- K^0_S}$ inclusive$)$** $= -0.65 \pm 0.12$
$C_{\phi K^0_S}$ $(B^0 \to \phi K^0_S) = 0.01 \pm 0.14$
$\boldsymbol{S_{\phi K^0_S}}$ **$\boldsymbol{(B^0 \to \phi K^0_S)}$** $= 0.59 \pm 0.14$
$C_{K_S K_S K_S}(B^0 \to K_S K_S K_S) = -0.23 \pm 0.14$
$S_{K_S K_S K_S}(B^0 \to K_S K_S K_S) = -0.5 \pm 0.6$ (S = 3.0)
$C_{K^0_S \pi^0 \gamma}(B^0 \to K^0_S \pi^0 \gamma) = 0.36 \pm 0.33$
$S_{K^0_S \pi^0 \gamma}(B^0 \to K^0_S \pi^0 \gamma) = -0.8 \pm 0.6$
$C_{K^0_S \pi^+ \pi^- \gamma}(B^0 \to K^0_S \pi^+ \pi^- \gamma) = -0.39 \pm 0.20$
$S_{K^0_S \pi^+ \pi^- \gamma}(B^0 \to K^0_S \pi^+ \pi^- \gamma) = 0.14 \pm 0.25$
$C_{K^{*0} \gamma}$ $(B^0 \to K^*(892)^0 \gamma) = -0.04 \pm 0.16$ (S = 1.2)
$S_{K^{*0} \gamma}$ $(B^0 \to K^*(892)^0 \gamma) = -0.15 \pm 0.22$
$C_{\eta K^0 \gamma}$ $(B^0 \to \eta K^0 \gamma) = -0.3 \pm 0.4$
$S_{\eta K^0 \gamma}$ $(B^0 \to \eta K^0 \gamma) = -0.2 \pm 0.5$
$C_{K^0 \phi \gamma}$ $(B^0 \to K^0 \phi \gamma) = -0.3 \pm 0.6$
$S_{K^0 \phi \gamma}$ $(B^0 \to K^0 \phi \gamma) = 0.7^{+0.7}_{-1.1}$
$C(B^0 \to K^0_S \rho^0 \gamma) = -0.05 \pm 0.19$
$S(B^0 \to K^0_S \rho^0 \gamma) = -0.04 \pm 0.23$
$C\,(B^0 \to \rho^0 \gamma) = 0.4 \pm 0.5$
$S\,(B^0 \to \rho^0 \gamma) = -0.8 \pm 0.7$
$\boldsymbol{C_{\pi\pi}}$ **$\boldsymbol{(B^0 \to \pi^+ \pi^-)}$** $= -0.31 \pm 0.05$
$\boldsymbol{S_{\pi\pi}}$ **$\boldsymbol{(B^0 \to \pi^+ \pi^-)}$** $= -0.67 \pm 0.06$
$C_{\pi^0 \pi^0}(B^0 \to \pi^0 \pi^0) = -0.33 \pm 0.22$
$C_{\rho\pi}$ $(B^0 \to \rho^+ \pi^-) = -0.03 \pm 0.07$ (S = 1.2)

$S_{\rho\pi}$ $(B^0 \rightarrow \rho^+\pi^-) = 0.05 \pm 0.07$
$\boldsymbol{\Delta C_{\rho\pi}}$ $\boldsymbol{(B^0 \rightarrow \rho^+\pi^-)} = 0.27 \pm 0.06$
$\Delta S_{\rho\pi}$ $(B^0 \rightarrow \rho^+\pi^-) = 0.01 \pm 0.08$
$C_{\rho^0\pi^0}$ $(B^0 \rightarrow \rho^0\pi^0) = 0.27 \pm 0.24$
$S_{\rho^0\pi^0}$ $(B^0 \rightarrow \rho^0\pi^0) = -0.23 \pm 0.34$
$C_{a_1\pi}$ $(B^0 \rightarrow a_1(1260)^+\pi^-) = -0.05 \pm 0.11$
$S_{a_1\pi}$ $(B^0 \rightarrow a_1(1260)^+\pi^-) = -0.2 \pm 0.4$ (S = 3.2)
$\boldsymbol{\Delta C_{a_1\pi}}$ $\boldsymbol{(B^0 \rightarrow a_1(1260)^+\pi^-)} = 0.43 \pm 0.14$ (S = 1.3)
$\Delta S_{a_1\pi}$ $(B^0 \rightarrow a_1(1260)^+\pi^-) = -0.11 \pm 0.12$
C $(B^0 \rightarrow b_1^- K^+) = -0.22 \pm 0.24$
$\boldsymbol{\Delta C}$ $\boldsymbol{(B^0 \rightarrow b_1^- \pi^+)} = -1.04 \pm 0.24$
$C_{\rho^0\rho^0}$ $(B^0 \rightarrow \rho^0\rho^0) = 0.2 \pm 0.9$
$S_{\rho^0\rho^0}$ $(B^0 \rightarrow \rho^0\rho^0) = 0.3 \pm 0.7$
$C_{\rho\rho}$ $(B^0 \rightarrow \rho^+\rho^-) = 0.00 \pm 0.09$
$S_{\rho\rho}$ $(B^0 \rightarrow \rho^+\rho^-) = -0.14 \pm 0.13$
$\left|\lambda\right|$ $(B^0 \rightarrow J/\psi K^*(892)^0) <$ 0.25, CL = 95%
$\cos 2\beta$ $(B^0 \rightarrow J/\psi K^*(892)^0) = 1.7^{+0.7}_{-0.9}$ (S = 1.6)
$\cos 2\beta$ $(B^0 \rightarrow [K^0_S\pi^+\pi^-]_{D^{(*)}} h^0) = 0.84 \pm 0.31$
$(S_+ + S_-)/2$ $(B^0 \rightarrow D^{*-}\pi^+) = -0.039 \pm 0.011$
$(S_- - S_+)/2$ $(B^0 \rightarrow D^{*-}\pi^+) = -0.009 \pm 0.015$
$(S_+ + S_-)/2$ $(B^0 \rightarrow D^-\pi^+) = -0.046 \pm 0.023$
$(S_- - S_+)/2$ $(B^0 \rightarrow D^-\pi^+) = -0.022 \pm 0.021$
$(S_+ + S_-)/2$ $(B^0 \rightarrow D^-\rho^+) = -0.024 \pm 0.032$
$(S_- - S_+)/2$ $(B^0 \rightarrow D^-\rho^+) = -0.10 \pm 0.06$
$C_{\eta_c K^0_S}$ $(B^0 \rightarrow \eta_c K^0_S) = 0.08 \pm 0.13$
$\boldsymbol{S_{\eta_c K^0_S}}$ $\boldsymbol{(B^0 \rightarrow \eta_c K^0_S)} = 0.93 \pm 0.17$
$C_{c\overline{c}K^{(*)0}}$ $(B^0 \rightarrow c\overline{c}K^{(*)0}) = (0.5 \pm 1.7) \times 10^{-2}$
$\boldsymbol{\sin(2\beta)} = 0.699 \pm 0.017$
$C_{J/\psi(nS)K^0}$ $(B^0 \rightarrow J/\psi(nS)K^0) = (0.5 \pm 2.0) \times 10^{-2}$
$\boldsymbol{S_{J/\psi(nS)K^0}}$ $\boldsymbol{(B^0 \rightarrow J/\psi(nS)K^0)} = 0.701 \pm 0.017$
$C_{J/\psi K^{*0}}$ $(B^0 \rightarrow J/\psi K^{*0}) = 0.03 \pm 0.10$
$S_{J/\psi K^{*0}}$ $(B^0 \rightarrow J/\psi K^{*0}) = 0.60 \pm 0.25$
$C_{\chi_{c0}K^0_S}$ $(B^0 \rightarrow \chi_{c0}K^0_S) = -0.3^{+0.5}_{-0.4}$
$S_{\chi_{c0}K^0_S}$ $(B^0 \rightarrow \chi_{c0}K^0_S) = -0.7 \pm 0.5$
$C_{\chi_{c1}K^0_S}$ $(B^0 \rightarrow \chi_{c1}K^0_S) = 0.06 \pm 0.07$
$\boldsymbol{S_{\chi_{c1}K^0_S}}$ $\boldsymbol{(B^0 \rightarrow \chi_{c1}K^0_S)} = 0.63 \pm 0.10$
$\sin(2\beta_{\rm eff})(B^0 \rightarrow \phi K^0) = 0.22 \pm 0.30$
$\sin(2\beta_{\rm eff})(B^0 \rightarrow \phi K^*_0(1430)^0) = 0.97^{+0.03}_{-0.52}$
$\boldsymbol{\sin(2\beta_{\rm eff})(B^0 \rightarrow K^+K^-K^0_S)} = 0.77^{+0.13}_{-0.12}$
$\sin(2\beta_{\rm eff})(B^0 \rightarrow [K^0_S\pi^+\pi^-]_{D^{(*)}} h^0) = 0.37 \pm 0.22$
$\beta_{\rm eff}(B^0 \rightarrow [K^0_S\pi^+\pi^-]_{D^{(*)}} h^0) = (12 \pm 8)^\circ$
$2\beta_{\rm eff}(B^0 \rightarrow J/\psi\rho^0) = (42^{+10}_{-11})^\circ$
$\left|\lambda\right|$ $(B^0 \rightarrow [K^0_S\pi^+\pi^-]_{D^{(*)}} h^0) = 1.01 \pm 0.08$
$\left|\sin(2\beta + \gamma)\right| >$ 0.40, CL = 90%
$2\beta + \gamma = (83 \pm 60)^\circ$
$\alpha = (93 \pm 5)^\circ$

$x_+(B^0 \to D K^{*0}) = 0.04 \pm 0.17$
$x_-(B^0 \to D K^{*0}) = -0.16 \pm 0.14$
$y_+(B^0 \to D K^{*0}) = -0.68 \pm 0.22$
$y_-(B^0 \to D K^{*0}) = 0.20 \pm 0.25$ (S = 1.2)
$r_{B^0}(B^0 \to D K^{*0}) = 0.223^{+0.041}_{-0.045}$
$\delta_{B^0}(B^0 \to D K^{*0}) = (193^{+27}_{-21})^\circ$

$\overline{B}^0$ modes are charge conjugates of the modes below. Reactions indicate the weak decay vertex and do not include mixing. Modes which do not identify the charge state of the B are listed in the $B^\pm/B^0$ ADMIXTURE section.

The branching fractions listed below assume 50% $B^0\overline{B}^0$ and 50% B^+B^- production at the $\Upsilon(4S)$. We have attempted to bring older measurements up to date by rescaling their assumed $\Upsilon(4S)$ production ratio to 50:50 and their assumed D, D_s, D^*, and ψ branching ratios to current values whenever this would affect our averages and best limits significantly.

Indentation is used to indicate a subchannel of a previous reaction. All resonant subchannels have been corrected for resonance branching fractions to the final state so the sum of the subchannel branching fractions can exceed that of the final state.
For inclusive branching fractions, *e.g.*, $B \to D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

B^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\ell^+\nu_\ell$ anything	[sss]	(10.33 ± 0.28) %		–
$e^+\nu_e X_c$		(10.1 ± 0.4) %		–
$D\ell^+\nu_\ell$ anything		(9.1 ± 0.8) %		–
$D^-\ell^+\nu_\ell$	[sss]	(2.20 ± 0.10) %		2309
$D^-\tau^+\nu_\tau$		(1.03 ± 0.22) %		1909
$D^*(2010)^-\ell^+\nu_\ell$	[sss]	(4.88 ± 0.10) %		2257
$D^*(2010)^-\tau^+\nu_\tau$		(1.67 ± 0.13) %	S=1.1	1838
$\overline{D}^0\pi^-\ell^+\nu_\ell$		(4.3 ± 0.6) $\times 10^{-3}$		2308
$D_0^*(2400)^-\ell^+\nu_\ell$, $D_0^{*-} \to \overline{D}^0\pi^-$		(3.0 ± 1.2) $\times 10^{-3}$	S=1.8	–
$D_2^*(2460)^-\ell^+\nu_\ell$, $D_2^{*-} \to \overline{D}^0\pi^-$		(1.21 ± 0.33) $\times 10^{-3}$	S=1.8	2065
$\overline{D}^{(*)} n\pi\ell^+\nu_\ell (n \geq 1)$		(2.3 ± 0.4) %		–
$\overline{D}^{*0}\pi^-\ell^+\nu_\ell$		(4.9 ± 0.8) $\times 10^{-3}$		2256
$D_1(2420)^-\ell^+\nu_\ell$, $D_1^- \to \overline{D}^{*0}\pi^-$		(2.80 ± 0.28) $\times 10^{-3}$		–
$D_1'(2430)^-\ell^+\nu_\ell$, $D_1'^- \to \overline{D}^{*0}\pi^-$		(3.1 ± 0.9) $\times 10^{-3}$		–
$D_2^*(2460)^-\ell^+\nu_\ell$, $D_2^{*-} \to \overline{D}^{*0}\pi^-$		(6.8 ± 1.2) $\times 10^{-4}$		2065
$D^-\pi^+\pi^-\ell^+\nu_\ell$		(1.3 ± 0.5) $\times 10^{-3}$		2299
$D^{*-}\pi^+\pi^-\ell^+\nu_\ell$		(1.4 ± 0.5) $\times 10^{-3}$		2247
$\rho^-\ell^+\nu_\ell$	[sss]	(2.94 ± 0.21) $\times 10^{-4}$		2583
$\pi^-\ell^+\nu_\ell$	[sss]	(1.50 ± 0.06) $\times 10^{-4}$		2638
$\pi^-\tau^+\nu_\tau$		< 2.5 $\times 10^{-4}$	CL=90%	2338
Inclusive modes				
$K^\pm$ anything		(78 ± 8) %		–
$D^0 X$		(8.1 ± 1.5) %		–
$\overline{D}^0 X$		(47.4 ± 2.8) %		–
$D^+ X$		< 3.9 %	CL=90%	–
$D^- X$		(36.9 ± 3.3) %		–

$D_s^+ X$	$(10.3 \begin{smallmatrix} +2.1 \\ -1.8 \end{smallmatrix})$ %		–
$D_s^- X$	$<$ 2.6 %	CL=90%	–
$\Lambda_c^+ X$	$<$ 3.1 %	CL=90%	–
$\overline{\Lambda}_c^- X$	$(5.0 \begin{smallmatrix} +2.1 \\ -1.5 \end{smallmatrix})$ %		–
$\overline{c} X$	(95 ± 5) %		–
$c X$	(24.6 ± 3.1) %		–
$\overline{c}/c X$	(119 ± 6) %		–
D, D^*, or D_s modes			
$D^- \pi^+$	$(2.52 \pm 0.13) \times 10^{-3}$	S=1.1	2306
$D^- \rho^+$	$(7.9 \pm 1.3) \times 10^{-3}$		2235
$D^- K^0 \pi^+$	$(4.9 \pm 0.9) \times 10^{-4}$		2259
$D^- K^*(892)^+$	$(4.5 \pm 0.7) \times 10^{-4}$		2211
$D^- \omega \pi^+$	$(2.8 \pm 0.6) \times 10^{-3}$		2204
$D^- K^+$	$(1.86 \pm 0.20) \times 10^{-4}$		2279
$D^- K^+ \pi^+ \pi^-$	$(3.5 \pm 0.8) \times 10^{-4}$		2236
$D^- K^+ \overline{K}^0$	$< 3.1 \times 10^{-4}$	CL=90%	2188
$D^- K^+ \overline{K}^*(892)^0$	$(8.8 \pm 1.9) \times 10^{-4}$		2070
$\overline{D}^0 \pi^+ \pi^-$	$(8.8 \pm 0.5) \times 10^{-4}$		2301
$D^*(2010)^- \pi^+$	$(2.74 \pm 0.13) \times 10^{-3}$		2255
$\overline{D}^0 K^+ K^-$	$(4.9 \pm 1.2) \times 10^{-5}$		2191
$D^- \pi^+ \pi^+ \pi^-$	$(6.0 \pm 0.7) \times 10^{-3}$	S=1.1	2287
$(D^- \pi^+ \pi^+ \pi^-)$ nonresonant	$(3.9 \pm 1.9) \times 10^{-3}$		2287
$D^- \pi^+ \rho^0$	$(1.1 \pm 1.0) \times 10^{-3}$		2206
$D^- a_1(1260)^+$	$(6.0 \pm 3.3) \times 10^{-3}$		2121
$D^*(2010)^- \pi^+ \pi^0$	(1.5 ± 0.5) %		2248
$D^*(2010)^- \rho^+$	$(2.2 \begin{smallmatrix} +1.8 \\ -2.7 \end{smallmatrix}) \times 10^{-3}$	S=5.2	2180
$D^*(2010)^- K^+$	$(2.12 \pm 0.15) \times 10^{-4}$		2226
$D^*(2010)^- K^0 \pi^+$	$(3.0 \pm 0.8) \times 10^{-4}$		2205
$D^*(2010)^- K^*(892)^+$	$(3.3 \pm 0.6) \times 10^{-4}$		2155
$D^*(2010)^- K^+ \overline{K}^0$	$< 4.7 \times 10^{-4}$	CL=90%	2131
$D^*(2010)^- K^+ \overline{K}^*(892)^0$	$(1.29 \pm 0.33) \times 10^{-3}$		2007
$D^*(2010)^- \pi^+ \pi^+ \pi^-$	$(7.21 \pm 0.29) \times 10^{-3}$		2235
$(D^*(2010)^- \pi^+ \pi^+ \pi^-)$ nonresonant	$(0.0 \pm 2.5) \times 10^{-3}$		2235
$D^*(2010)^- \pi^+ \rho^0$	$(5.7 \pm 3.2) \times 10^{-3}$		2150
$D^*(2010)^- a_1(1260)^+$	(1.30 ± 0.27) %		2061
$\overline{D}_1(2420)^0 \pi^- \pi^+$, $\overline{D}_1^0 \to D^{*-} \pi^+$	$(1.47 \pm 0.35) \times 10^{-4}$		–
$D^*(2010)^- K^+ \pi^- \pi^+$	$(4.7 \pm 0.4) \times 10^{-4}$		2181
$D^*(2010)^- \pi^+ \pi^+ \pi^- \pi^0$	(1.76 ± 0.27) %		2218
$D^{*-} 3\pi^+ 2\pi^-$	$(4.7 \pm 0.9) \times 10^{-3}$		2195
$\overline{D}^*(2010)^- \omega \pi^+$	$(2.46 \pm 0.18) \times 10^{-3}$	S=1.2	2148
$D_1(2430)^0 \omega$, $D_1^0 \to D^{*-} \pi^+$	$(2.7 \begin{smallmatrix} +0.8 \\ -0.4 \end{smallmatrix}) \times 10^{-4}$		1992
$\overline{D}^{*-} \rho(1450)^+$	$(1.07 \begin{smallmatrix} +0.40 \\ -0.34 \end{smallmatrix}) \times 10^{-3}$		–
$\overline{D}_1(2420)^0 \omega$	$(7.0 \pm 2.2) \times 10^{-5}$		1995
$\overline{D}_2^*(2460)^0 \omega$	$(4.0 \pm 1.4) \times 10^{-5}$		1975
$\overline{D}^{*-} b_1(1235)^-$, $b_1^- \to \omega \pi^-$	$< 7 \times 10^{-5}$	CL=90%	–
$\overline{D}^{**-} \pi^+$	[xxx] $(1.9 \pm 0.9) \times 10^{-3}$		–
$D_1(2420)^- \pi^+$, $D_1^- \to D^- \pi^+ \pi^-$	$(9.9 \begin{smallmatrix} +2.0 \\ -2.5 \end{smallmatrix}) \times 10^{-5}$		–

$D_1(2420)^- \pi^+$, $D_1^- \to D^{*-}\pi^+\pi^-$	$< 3.3 \times 10^{-5}$	CL=90%	–
$\overline{D}{}_2^*(2460)^- \pi^+$, $(D_2^*)^- \to D^0\pi^-$	$(2.38\pm 0.16) \times 10^{-4}$		2062
$\overline{D}{}_0^*(2400)^- \pi^+$, $(D_0^*)^- \to D^0\pi^-$	$(7.6\pm 0.8) \times 10^{-5}$		2090
$D_2^*(2460)^- \pi^+$, $(D_2^*)^- \to D^{*-}\pi^+\pi^-$	$< 2.4 \times 10^{-5}$	CL=90%	–
$\overline{D}{}_2^*(2460)^- \rho^+$	$< 4.9 \times 10^{-3}$	CL=90%	1974
$D^0 \overline{D}{}^0$	$(1.4\pm 0.7) \times 10^{-5}$		1868
$D^{*0} \overline{D}{}^0$	$< 2.9 \times 10^{-4}$	CL=90%	1794
$D^- D^+$	$(2.11\pm 0.18) \times 10^{-4}$		1864
$D^\pm D^{*\mp}$ (CP-averaged)	$(6.1\pm 0.6) \times 10^{-4}$		–
$D^- D_s^+$	$(7.2\pm 0.8) \times 10^{-3}$		1812
$D^*(2010)^- D_s^+$	$(8.0\pm 1.1) \times 10^{-3}$		1735
$D^- D_s^{*+}$	$(7.4\pm 1.6) \times 10^{-3}$		1732
$D^*(2010)^- D_s^{*+}$	(1.77 ± 0.14) %		1649
$D_{s0}(2317)^- K^+$, $D_{s0}^- \to D_s^-\pi^0$	$(4.2\pm 1.4) \times 10^{-5}$		2097
$D_{s0}(2317)^- \pi^+$, $D_{s0}^- \to D_s^-\pi^0$	$< 2.5 \times 10^{-5}$	CL=90%	2128
$D_{sJ}(2457)^- K^+$, $D_{sJ}^- \to D_s^-\pi^0$	$< 9.4 \times 10^{-6}$	CL=90%	–
$D_{sJ}(2457)^- \pi^+$, $D_{sJ}^- \to D_s^-\pi^0$	$< 4.0 \times 10^{-6}$	CL=90%	–
$D_s^- D_s^+$	$< 3.6 \times 10^{-5}$	CL=90%	1759
$D_s^{*-} D_s^+$	$< 1.3 \times 10^{-4}$	CL=90%	1674
$D_s^{*-} D_s^{*+}$	$< 2.4 \times 10^{-4}$	CL=90%	1583
$D_{s0}^*(2317)^+ D^-$, $D_{s0}^{*+} \to D_s^+\pi^0$	$(1.09\pm 0.16) \times 10^{-3}$		1602
$D_{s0}(2317)^+ D^-$, $D_{s0}^+ \to D_s^{*+}\gamma$	$< 9.5 \times 10^{-4}$	CL=90%	–
$D_{s0}(2317)^+ D^*(2010)^-$, $D_{s0}^+ \to D_s^+\pi^0$	$(1.5\pm 0.6) \times 10^{-3}$		1509
$D_{sJ}(2457)^+ D^-$	$(3.5\pm 1.1) \times 10^{-3}$		–
$D_{sJ}(2457)^+ D^-$, $D_{sJ}^+ \to D_s^+\gamma$	$(6.5\ ^{+1.7}_{-1.4}) \times 10^{-4}$		–
$D_{sJ}(2457)^+ D^-$, $D_{sJ}^+ \to D_s^{*+}\gamma$	$< 6.0 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+ D^-$, $D_{sJ}^+ \to D_s^+\pi^+\pi^-$	$< 2.0 \times 10^{-4}$	CL=90%	–
$D_{sJ}(2457)^+ D^-$, $D_{sJ}^+ \to D_s^+\pi^0$	$< 3.6 \times 10^{-4}$	CL=90%	–
$D^*(2010)^- D_{sJ}(2457)^+$	$(9.3\pm 2.2) \times 10^{-3}$		–
$D_{sJ}(2457)^+ D^*(2010)$, $D_{sJ}^+ \to D_s^+\gamma$	$(2.3\ ^{+0.9}_{-0.7}) \times 10^{-3}$		–
$D^- D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*0}K^+ + D^{*+}K^0$	$(2.8\pm 0.7) \times 10^{-4}$		1444
$D^- D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*0}K^+$	$(1.7\pm 0.6) \times 10^{-4}$		1444
$D^- D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*+}K^0$	$(2.6\pm 1.1) \times 10^{-4}$		1444
$D^*(2010)^- D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*0}K^+ + D^{*+}K^0$	$(5.0\pm 1.4) \times 10^{-4}$		1336
$D^*(2010)^- D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*0}K^+$	$(3.3\pm 1.1) \times 10^{-4}$		1336
$D^{*-} D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*+}K^0$	$(5.0\pm 1.7) \times 10^{-4}$		1336
$D^- D_{sJ}(2573)^+$, $D_{sJ}^+ \to D^0K^+$	$(3.4\pm 1.8) \times 10^{-5}$		1414

$D^*(2010)^- D_{sJ}(2573)^+$, $D_{sJ}^+ \to D^0 K^+$	$<$ 2	$\times 10^{-4}$	CL=90%	1304
$D^- D_{sJ}(2700)^+$, $D_{sJ}^+ \to D^0 K^+$	(7.1 ± 1.2)	$\times 10^{-4}$		–
$D^+ \pi^-$	(7.4 ± 1.3)	$\times 10^{-7}$		2306
$D_s^+ \pi^-$	(2.16± 0.26)	$\times 10^{-5}$		2270
$D_s^{*+} \pi^-$	(2.1 ± 0.4)	$\times 10^{-5}$	S=1.4	2215
$D_s^+ \rho^-$	$<$ 2.4	$\times 10^{-5}$	CL=90%	2197
$D_s^{*+} \rho^-$	(4.1 ± 1.3)	$\times 10^{-5}$		2138
$D_s^+ a_0^-$	$<$ 1.9	$\times 10^{-5}$	CL=90%	–
$D_s^{*+} a_0^-$	$<$ 3.6	$\times 10^{-5}$	CL=90%	–
$D_s^+ a_1(1260)^-$	$<$ 2.1	$\times 10^{-3}$	CL=90%	2080
$D_s^{*+} a_1(1260)^-$	$<$ 1.7	$\times 10^{-3}$	CL=90%	2015
$D_s^+ a_2^-$	$<$ 1.9	$\times 10^{-4}$	CL=90%	–
$D_s^{*+} a_2^-$	$<$ 2.0	$\times 10^{-4}$	CL=90%	–
$D_s^- K^+$	(2.7 ± 0.5)	$\times 10^{-5}$	S=2.7	2242
$D_s^{*-} K^+$	(2.19± 0.30)	$\times 10^{-5}$		2185
$D_s^- K^*(892)^+$	(3.5 ± 1.0)	$\times 10^{-5}$		2172
$D_s^{*-} K^*(892)^+$	(3.2 $^{+1.5}_{-1.3}$)	$\times 10^{-5}$		2112
$D_s^- \pi^+ K^0$	(9.7 ± 1.4)	$\times 10^{-5}$		2222
$D_s^{*-} \pi^+ K^0$	$<$ 1.10	$\times 10^{-4}$	CL=90%	2164
$D_s^- K^+ \pi^+ \pi^-$	(1.7 ± 0.5)	$\times 10^{-4}$		2198
$D_s^- \pi^+ K^*(892)^0$	$<$ 3.0	$\times 10^{-3}$	CL=90%	2138
$D_s^{*-} \pi^+ K^*(892)^0$	$<$ 1.6	$\times 10^{-3}$	CL=90%	2076
$\overline{D}^0 K^0$	(5.2 ± 0.7)	$\times 10^{-5}$		2280
$\overline{D}^0 K^+ \pi^-$	(8.8 ± 1.7)	$\times 10^{-5}$		2261
$\quad \overline{D}^0 K^*(892)^0$	(4.5 ± 0.6)	$\times 10^{-5}$		2213
$\quad \overline{D}^0 K^*(1410)^0$	$<$ 6.7	$\times 10^{-5}$	CL=90%	2059
$\quad \overline{D}^0 K_0^*(1430)^0$	(7 ± 7)	$\times 10^{-6}$		2057
$\quad \overline{D}^0 K_2^*(1430)^0$	(2.1 ± 0.9)	$\times 10^{-5}$		2057
$\quad D_0^*(2400)^-$, $D_0^{*-} \to \overline{D}^0 \pi^-$	(1.9 ± 0.9)	$\times 10^{-5}$		–
$\quad D_2^*(2460)^- K^+$, $D_2^{*-} \to \overline{D}^0 \pi^-$	(2.03± 0.35)	$\times 10^{-5}$		2029
$\quad D_3^*(2760)^- K^+$, $D_3^{*-} \to \overline{D}^0 \pi^-$	$<$ 1.0	$\times 10^{-6}$	CL=90%	–
$\quad \overline{D}^0 K^+ \pi^-$ non-resonant	$<$ 3.7	$\times 10^{-5}$	CL=90%	–
$\overline{D}^0 \pi^0$	(2.63± 0.14)	$\times 10^{-4}$		2308
$\overline{D}^0 \rho^0$	(3.21± 0.21)	$\times 10^{-4}$		2237
$\overline{D}^0 f_2$	(1.56± 0.21)	$\times 10^{-4}$		–
$\overline{D}^0 \eta$	(2.36± 0.32)	$\times 10^{-4}$	S=2.5	2274
$\overline{D}^0 \eta'$	(1.38± 0.16)	$\times 10^{-4}$	S=1.3	2198
$\overline{D}^0 \omega$	(2.54± 0.16)	$\times 10^{-4}$		2235
$D^0 \phi$	$<$ 1.16	$\times 10^{-5}$	CL=90%	2183
$D^0 K^+ \pi^-$	(5.3 ± 3.2)	$\times 10^{-6}$		2261
$\quad D^0 K^*(892)^0$	$<$ 1.1	$\times 10^{-5}$	CL=90%	2213
$\overline{D}^{*0} \gamma$	$<$ 2.5	$\times 10^{-5}$	CL=90%	2258
$\overline{D}^*(2007)^0 \pi^0$	(2.2 ± 0.6)	$\times 10^{-4}$	S=2.6	2256
$\overline{D}^*(2007)^0 \rho^0$	$<$ 5.1	$\times 10^{-4}$	CL=90%	2182
$\overline{D}^*(2007)^0 \eta$	(2.3 ± 0.6)	$\times 10^{-4}$	S=2.8	2220
$\overline{D}^*(2007)^0 \eta'$	(1.40± 0.22)	$\times 10^{-4}$		2141
$\overline{D}^*(2007)^0 \pi^+ \pi^-$	(6.2 ± 2.2)	$\times 10^{-4}$		2249
$\overline{D}^*(2007)^0 K^0$	(3.6 ± 1.2)	$\times 10^{-5}$		2227

$\overline{D}^*(2007)^0 K^*(892)^0$	$< 6.9 \times 10^{-5}$		CL=90%	2157
$D^*(2007)^0 K^*(892)^0$	$< 4.0 \times 10^{-5}$		CL=90%	2157
$D^*(2007)^0 \pi^+\pi^+\pi^-\pi^-$	$(2.7 \pm 0.5) \times 10^{-3}$			2219
$D^*(2010)^+ D^*(2010)^-$	$(8.0 \pm 0.6) \times 10^{-4}$			1711
$\overline{D}^*(2007)^0 \omega$	$(3.6 \pm 1.1) \times 10^{-4}$		S=3.1	2180
$D^*(2010)^+ D^-$	$(6.1 \pm 1.5) \times 10^{-4}$		S=1.6	1790
$D^*(2007)^0 \overline{D}^*(2007)^0$	$< 9 \times 10^{-5}$		CL=90%	1715
$D^- D^0 K^+$	$(1.07 \pm 0.11) \times 10^{-3}$			1574
$D^- D^*(2007)^0 K^+$	$(3.5 \pm 0.4) \times 10^{-3}$			1478
$D^*(2010)^- D^0 K^+$	$(2.47 \pm 0.21) \times 10^{-3}$			1479
$D^*(2010)^- D^*(2007)^0 K^+$	(1.06 ± 0.09) %			1366
$D^- D^+ K^0$	$(7.5 \pm 1.7) \times 10^{-4}$			1568
$D^*(2010)^- D^+ K^0 + D^- D^*(2010)^+ K^0$	$(6.4 \pm 0.5) \times 10^{-3}$			1473
$D^*(2010)^- D^*(2010)^+ K^0$	$(8.1 \pm 0.7) \times 10^{-3}$			1360
$D^{*-} D_{s1}(2536)^+$, $D_{s1}^+ \to D^{*+} K^0$	$(8.0 \pm 2.4) \times 10^{-4}$			1336
$\overline{D}^0 D^0 K^0$	$(2.7 \pm 1.1) \times 10^{-4}$			1574
$\overline{D}^0 D^*(2007)^0 K^0 + \overline{D}^*(2007)^0 D^0 K^0$	$(1.1 \pm 0.5) \times 10^{-3}$			1478
$\overline{D}^*(2007)^0 D^*(2007)^0 K^0$	$(2.4 \pm 0.9) \times 10^{-3}$			1365
$(\overline{D}+\overline{D}^*)(D+D^*)K$	(3.68 ± 0.26) %			–

Charmonium modes

$\eta_c K^0$	$(7.9 \pm 1.2) \times 10^{-4}$			1751
$\eta_c K^*(892)^0$	$(6.9 \pm 0.9) \times 10^{-4}$			1646
$\eta_c(2S) K^{*0}$	$< 3.9 \times 10^{-4}$		CL=90%	1159
$h_c(1P) K^{*0}$	$< 4 \times 10^{-4}$		CL=90%	1253
$J/\psi(1S) K^0$	$(8.73 \pm 0.32) \times 10^{-4}$			1683
$J/\psi(1S) K^+\pi^-$	$(1.15 \pm 0.05) \times 10^{-3}$			1652
$J/\psi(1S) K^*(892)^0$	$(1.27 \pm 0.05) \times 10^{-3}$			1571
$J/\psi(1S) \eta K^0_S$	$(5.4 \pm 0.9) \times 10^{-5}$			1508
$J/\psi(1S) \eta' K^0_S$	$< 2.5 \times 10^{-5}$		CL=90%	1271
$J/\psi(1S) \phi K^0$	$(4.9 \pm 1.0) \times 10^{-5}$		S=1.3	1224
$J/\psi(1S) \omega K^0$	$(2.3 \pm 0.4) \times 10^{-4}$			1386
$\chi_{c1}(3872) K^0$, $\chi_{c1} \to J/\psi\omega$	$(6.0 \pm 3.2) \times 10^{-6}$			1140
$X(3915)$, $X \to J/\psi\omega$	$(2.1 \pm 0.9) \times 10^{-5}$			1102
$J/\psi(1S) K(1270)^0$	$(1.3 \pm 0.5) \times 10^{-3}$			1391
$J/\psi(1S) \pi^0$	$(1.76 \pm 0.16) \times 10^{-5}$		S=1.1	1728
$J/\psi(1S) \eta$	$(1.08 \pm 0.23) \times 10^{-5}$		S=1.5	1673
$J/\psi(1S) \pi^+\pi^-$	$(3.96 \pm 0.17) \times 10^{-5}$			1716
$J/\psi(1S) \pi^+\pi^-$ nonresonant	$< 1.2 \times 10^{-5}$		CL=90%	1716
$J/\psi(1S) f_0(500)$, $f_0 \to \pi\pi$	$(8.0\ ^{+1.1}_{-0.9}) \times 10^{-6}$			–
$J/\psi(1S) f_2$	$(3.3 \pm 0.5) \times 10^{-6}$		S=1.5	–
$J/\psi(1S) \rho^0$	$(2.55\ ^{+0.18}_{-0.16}) \times 10^{-5}$			1612
$J/\psi(1S) f_0(980)$, $f_0 \to \pi^+\pi^-$	$< 1.1 \times 10^{-6}$		CL=90%	–
$J/\psi(1S) \rho(1450)^0$, $\rho^0 \to \pi\pi$	$(2.9\ ^{+1.6}_{-0.7}) \times 10^{-6}$			–
$J/\psi \rho(1700)^0$, $\rho^0 \to \pi^+\pi^-$	$(2.0 \pm 1.3) \times 10^{-6}$			–
$J/\psi(1S) \omega$	$(1.8\ ^{+0.7}_{-0.5}) \times 10^{-5}$			1609
$J/\psi(1S) K^+K^-$	$(2.51 \pm 0.35) \times 10^{-6}$			1533
$J/\psi(1S) a_0(980)$, $a_0 \to K^+K^-$	$(4.7 \pm 3.4) \times 10^{-7}$			–
$J/\psi(1S) \phi$	$< 1.9 \times 10^{-7}$		CL=90%	1520

$J/\psi(1S)\eta'(958)$	$(7.6 \pm 2.4) \times 10^{-6}$		1546
$J/\psi(1S)K^0\pi^+\pi^-$	$(4.4 \pm 0.4) \times 10^{-4}$		1611
$J/\psi(1S)K^0K^-\pi^+ +$ c.c.	$< 2.1 \times 10^{-5}$	CL=90%	1467
$J/\psi(1S)K^0K^+K^-$	$(2.5 \pm 0.7) \times 10^{-5}$	S=1.8	1249
$J/\psi(1S)K^0\rho^0$	$(5.4 \pm 3.0) \times 10^{-4}$		1390
$J/\psi(1S)K^*(892)^+\pi^-$	$(8 \pm 4) \times 10^{-4}$		1514
$J/\psi(1S)\pi^+\pi^-\pi^+\pi^-$	$(1.43 \pm 0.12) \times 10^{-5}$		1670
$J/\psi(1S)f_1(1285)$	$(8.2 \pm 2.1) \times 10^{-6}$		1385
$J/\psi(1S)K^*(892)^0\pi^+\pi^-$	$(6.6 \pm 2.2) \times 10^{-4}$		1447
$\chi_{c1}(3872)^-K^+$	$< 5 \times 10^{-4}$	CL=90%	–
$\chi_{c1}(3872)^-K^+$, $\chi_{c1}(3872)^- \to J/\psi(1S)\pi^-\pi^0$ [yyy]	$< 4.2 \times 10^{-6}$	CL=90%	–
$\chi_{c1}(3872)K^0$, $\chi_{c1} \to J/\psi\pi^+\pi^-$	$(4.3 \pm 1.3) \times 10^{-6}$		1140
$\chi_{c1}(3872)K^0$, $\chi_{c1} \to J/\psi\gamma$	$< 2.4 \times 10^{-6}$	CL=90%	1140
$\chi_{c1}(3872)K^*(892)^0$, $\chi_{c1} \to J/\psi\gamma$	$< 2.8 \times 10^{-6}$	CL=90%	940
$\chi_{c1}(3872)K^0$, $\chi_{c1} \to \psi(2S)\gamma$	$< 6.62 \times 10^{-6}$	CL=90%	1140
$\chi_{c1}(3872)K^*(892)^0$, $\chi_{c1} \to \psi(2S)\gamma$	$< 4.4 \times 10^{-6}$	CL=90%	940
$\chi_{c1}(3872)K^0$, $\chi_{c1} \to D^0\overline{D}^0\pi^0$	$(1.7 \pm 0.8) \times 10^{-4}$		1140
$\chi_{c1}(3872)K^0$, $\chi_{c1} \to \overline{D}^{*0}D^0$	$(1.2 \pm 0.4) \times 10^{-4}$		1140
$\chi_{c1}(3872)K^+\pi^-$, $\chi_{c1} \to J/\psi\pi^+\pi^-$	$(7.9 \pm 1.4) \times 10^{-6}$		–
$\chi_{c1}(3872)K^*(892)^0$, $\chi_{c1} \to J/\psi\pi^+\pi^-$	$(4.0 \pm 1.5) \times 10^{-6}$		–
$Z_c(4430)^\pm K^\mp$, $Z_c^\pm \to \psi(2S)\pi^\pm$	$(6.0 {}^{+3.0}_{-2.4}) \times 10^{-5}$		583
$Z_c(4430)^\pm K^\mp$, $Z_c^\pm \to J/\psi\pi^\pm$	$(5.4 {}^{+4.0}_{-1.2}) \times 10^{-6}$		583
$Z_c(3900)^\pm K^\mp$, $Z_c^\pm \to J/\psi\pi^\pm$	$< 9 \times 10^{-7}$		–
$Z_c(4200)^\pm K^\mp$, $X^\pm \to J/\psi\pi^\pm$	$(2.2 {}^{+1.3}_{-0.8}) \times 10^{-5}$		–
$J/\psi(1S)p\overline{p}$	$< 5.2 \times 10^{-7}$	CL=90%	862
$J/\psi(1S)\gamma$	$< 1.5 \times 10^{-6}$	CL=90%	1732
$J/\psi(1S)\overline{D}^0$	$< 1.3 \times 10^{-5}$	CL=90%	877
$\psi(2S)\pi^0$	$(1.17 \pm 0.19) \times 10^{-5}$		1348
$\psi(2S)K^0$	$(5.8 \pm 0.5) \times 10^{-4}$		1283
$\psi(3770)K^0$, $\psi \to \overline{D}^0D^0$	$< 1.23 \times 10^{-4}$	CL=90%	1217
$\psi(3770)K^0$, $\psi \to D^-D^+$	$< 1.88 \times 10^{-4}$	CL=90%	1217
$\psi(2S)\pi^+\pi^-$	$(2.22 \pm 0.35) \times 10^{-5}$		1331
$\psi(2S)K^+\pi^-$	$(5.8 \pm 0.4) \times 10^{-4}$		1239
$\psi(2S)K^*(892)^0$	$(5.9 \pm 0.4) \times 10^{-4}$		1116
$\chi_{c0}K^0$	$(1.46 \pm 0.27) \times 10^{-4}$		1477
$\chi_{c0}K^*(892)^0$	$(1.7 \pm 0.4) \times 10^{-4}$		1342
$\chi_{c1}\pi^0$	$(1.12 \pm 0.28) \times 10^{-5}$		1468
$\chi_{c1}K^0$	$(3.93 \pm 0.27) \times 10^{-4}$		1411
$\chi_{c1}\pi^-K^+$	$(4.97 \pm 0.30) \times 10^{-4}$		1371
$\chi_{c1}K^*(892)^0$	$(2.38 \pm 0.19) \times 10^{-4}$	S=1.2	1265
$X(4051)^-K^+$, $X^- \to \chi_{c1}\pi^-$	$(3.0 {}^{+4.0}_{-1.8}) \times 10^{-5}$		–
$X(4248)^-K^+$, $X^- \to \chi_{c1}\pi^-$	$(4.0 {}^{+20.0}_{-1.0}) \times 10^{-5}$		–
$\chi_{c1}\pi^+\pi^-K^0$	$(3.2 \pm 0.5) \times 10^{-4}$		1318
$\chi_{c1}\pi^-\pi^0K^+$	$(3.5 \pm 0.6) \times 10^{-4}$		1321
$\chi_{c2}K^0$	$< 1.5 \times 10^{-5}$	CL=90%	1379

$\chi_{c2} K^*(892)^0$		$(4.9 \pm 1.2) \times 10^{-5}$	S=1.1	1228
$\chi_{c2} \pi^- K^+$		$(7.2 \pm 1.0) \times 10^{-5}$		1338
$\chi_{c2} \pi^+ \pi^- K^0$		$< 1.70 \times 10^{-4}$	CL=90%	1282
$\chi_{c2} \pi^- \pi^0 K^+$		$< 7.4 \times 10^{-5}$	CL=90%	1286
K or K^* modes				
$K^+ \pi^-$		$(1.96 \pm 0.05) \times 10^{-5}$		2615
$K^0 \pi^0$		$(9.9 \pm 0.5) \times 10^{-6}$		2615
$\eta' K^0$		$(6.6 \pm 0.4) \times 10^{-5}$	S=1.4	2528
$\eta' K^*(892)^0$		$(2.8 \pm 0.6) \times 10^{-6}$		2472
$\eta' K_0^*(1430)^0$		$(6.3 \pm 1.6) \times 10^{-6}$		2346
$\eta' K_2^*(1430)^0$		$(1.37 \pm 0.32) \times 10^{-5}$		2346
ηK^0		$(1.23^{+0.27}_{-0.24}) \times 10^{-6}$		2587
$\eta K^*(892)^0$		$(1.59 \pm 0.10) \times 10^{-5}$		2534
$\eta K_0^*(1430)^0$		$(1.10 \pm 0.22) \times 10^{-5}$		2415
$\eta K_2^*(1430)^0$		$(9.6 \pm 2.1) \times 10^{-6}$		2414
ωK^0		$(4.8 \pm 0.4) \times 10^{-6}$		2557
$a_0(980)^0 K^0,\ a_0^0 \rightarrow \eta \pi^0$		$< 7.8 \times 10^{-6}$	CL=90%	–
$b_1^0 K^0,\ b_1^0 \rightarrow \omega \pi^0$		$< 7.8 \times 10^{-6}$	CL=90%	–
$a_0(980)^\pm K^\mp,\ a_0^\pm \rightarrow \eta \pi^\pm$		$< 1.9 \times 10^{-6}$	CL=90%	–
$b_1^- K^+,\ b_1^- \rightarrow \omega \pi^-$		$(7.4 \pm 1.4) \times 10^{-6}$		–
$b_1^0 K^{*0},\ b_1^0 \rightarrow \omega \pi^0$		$< 8.0 \times 10^{-6}$	CL=90%	–
$b_1^- K^{*+},\ b_1^- \rightarrow \omega \pi^-$		$< 5.0 \times 10^{-6}$	CL=90%	–
$a_0(1450)^\pm K^\mp,\ a_0^\pm \rightarrow \eta \pi^\pm$		$< 3.1 \times 10^{-6}$	CL=90%	–
$K_S^0 X^0$ (Familon)		$< 5.3 \times 10^{-5}$	CL=90%	–
$\omega K^*(892)^0$		$(2.0 \pm 0.5) \times 10^{-6}$		2503
$\omega (K\pi)_0^{*0}$		$(1.84 \pm 0.25) \times 10^{-5}$		–
$\omega K_0^*(1430)^0$		$(1.60 \pm 0.34) \times 10^{-5}$		2380
$\omega K_2^*(1430)^0$		$(1.01 \pm 0.23) \times 10^{-5}$		2380
$\omega K^+ \pi^-$ nonresonant		$(5.1 \pm 1.0) \times 10^{-6}$		2542
$K^+ \pi^- \pi^0$		$(3.78 \pm 0.32) \times 10^{-5}$		2609
$K^+ \rho^-$		$(7.0 \pm 0.9) \times 10^{-6}$		2559
$K^+ \rho(1450)^-$		$(2.4 \pm 1.2) \times 10^{-6}$		–
$K^+ \rho(1700)^-$		$(6 \pm 7) \times 10^{-7}$		–
$(K^+ \pi^- \pi^0)$ non-resonant		$(2.8 \pm 0.6) \times 10^{-6}$		–
$(K\pi)_0^{*+} \pi^-,\ (K\pi)_0^{*+} \rightarrow K^+ \pi^0$		$(3.4 \pm 0.5) \times 10^{-5}$		–
$(K\pi)_0^{*0} \pi^0,\ (K\pi)_0^{*0} \rightarrow K^+ \pi^-$		$(8.6 \pm 1.7) \times 10^{-6}$		–
$K_2^*(1430)^0 \pi^0$		$< 4.0 \times 10^{-6}$	CL=90%	2445
$K^*(1680)^0 \pi^0$		$< 7.5 \times 10^{-6}$	CL=90%	2358
$K_x^{*0} \pi^0$	[bbaa]	$(6.1 \pm 1.6) \times 10^{-6}$		–
$K^0 \pi^+ \pi^-$		$(4.94 \pm 0.18) \times 10^{-5}$		2609
$K^0 \pi^+ \pi^-$ non-resonant		$(1.47^{+0.40}_{-0.26}) \times 10^{-5}$	S=2.1	–
$K^0 \rho^0$		$(4.7 \pm 0.6) \times 10^{-6}$		2558
$K^*(892)^+ \pi^-$		$(8.4 \pm 0.8) \times 10^{-6}$		2563
$K_0^*(1430)^+ \pi^-$		$(3.3 \pm 0.7) \times 10^{-5}$	S=2.0	–
$K_x^{*+} \pi^-$	[bbaa]	$(5.1 \pm 1.6) \times 10^{-6}$		–
$K^*(1410)^+ \pi^-,\ K^{*+} \rightarrow K^0 \pi^+$		$< 3.8 \times 10^{-6}$	CL=90%	–
$f_0(980) K^0,\ f_0 \rightarrow \pi^+ \pi^-$		$(7.0 \pm 0.9) \times 10^{-6}$		2522
$f_2(1270) K^0$		$(2.7 ^{+1.3}_{-1.2}) \times 10^{-6}$		2459
$f_x(1300) K0, f_x \rightarrow \pi^+ \pi^-$		$(1.8 \pm 0.7) \times 10^{-6}$		–

$K^*(892)^0\pi^0$		$(3.3 \pm 0.6) \times 10^{-6}$		2563
$K_2^*(1430)^+\pi^-$		$< 6 \times 10^{-6}$	CL=90%	2445
$K^*(1680)^+\pi^-$		$< 1.0 \times 10^{-5}$	CL=90%	2358
$K^+\pi^-\pi^+\pi^-$	[ccaa]	$< 2.3 \times 10^{-4}$	CL=90%	2600
$\rho^0 K^+\pi^-$		$(2.8 \pm 0.7) \times 10^{-6}$		2543
$f_0(980)K^+\pi^-$, $f_0 \to \pi\pi$		$(1.4 {}^{+0.5}_{-0.6}) \times 10^{-6}$		2506
$K^+\pi^-\pi^+\pi^-$ nonresonant		$< 2.1 \times 10^{-6}$	CL=90%	2600
$K^*(892)^0\pi^+\pi^-$		$(5.5 \pm 0.5) \times 10^{-5}$		2557
$K^*(892)^0\rho^0$		$(3.9 \pm 1.3) \times 10^{-6}$	S=1.9	2504
$K^*(892)^0 f_0(980)$, $f_0 \to \pi\pi$		$(3.9 {}^{+2.1}_{-1.8}) \times 10^{-6}$	S=3.9	2466
$K_1(1270)^+\pi^-$		$< 3.0 \times 10^{-5}$	CL=90%	2484
$K_1(1400)^+\pi^-$		$< 2.7 \times 10^{-5}$	CL=90%	2451
$a_1(1260)^- K^+$	[ccaa]	$(1.6 \pm 0.4) \times 10^{-5}$		2471
$K^*(892)^+\rho^-$		$(1.03 \pm 0.26) \times 10^{-5}$		2504
$K_0^*(1430)^+\rho^-$		$(2.8 \pm 1.2) \times 10^{-5}$		–
$K_1(1400)^0\rho^0$		$< 3.0 \times 10^{-3}$	CL=90%	2388
$K_0^*(1430)^0\rho^0$		$(2.7 \pm 0.6) \times 10^{-5}$		2381
$K_0^*(1430)^0 f_0(980)$, $f_0 \to \pi\pi$		$(2.7 \pm 0.9) \times 10^{-6}$		–
$K_2^*(1430)^0 f_0(980)$, $f_0 \to \pi\pi$		$(8.6 \pm 2.0) \times 10^{-6}$		–
K^+K^-		$(7.8 \pm 1.5) \times 10^{-8}$		2593
$K^0\overline{K}^0$		$(1.21 \pm 0.16) \times 10^{-6}$		2592
$K^0K^-\pi^+$		$(6.2 \pm 0.7) \times 10^{-6}$		2578
$K^*(892)^\pm K^\mp$		$< 4 \times 10^{-7}$	CL=90%	2540
$\overline{K}^{*0}K^0 + K^{*0}\overline{K}^0$		$< 9.6 \times 10^{-7}$	CL=90%	–
$K^+K^-\pi^0$		$(2.2 \pm 0.6) \times 10^{-6}$		2579
$K_S^0 K_S^0 \pi^0$		$< 9 \times 10^{-7}$	CL=90%	2578
$K_S^0 K_S^0 \eta$		$< 1.0 \times 10^{-6}$	CL=90%	2515
$K_S^0 K_S^0 \eta'$		$< 2.0 \times 10^{-6}$	CL=90%	2453
$K^0K^+K^-$		$(2.67 \pm 0.11) \times 10^{-5}$		2522
$K^0\phi$		$(7.3 \pm 0.7) \times 10^{-6}$		2516
$f_0(980)K^0$, $f_0 \to K^+K^-$		$(7.0 {}^{+3.5}_{-3.0}) \times 10^{-6}$		–
$f_0(1500)K^0$		$(1.3 {}^{+0.7}_{-0.5}) \times 10^{-5}$		2398
$f_2'(1525)^0 K^0$		$(3 {}^{+5}_{-4}) \times 10^{-7}$		–
$f_0(1710)K^0$, $f_0 \to K^+K^-$		$(4.4 \pm 0.9) \times 10^{-6}$		–
$K^0K^+K^-$ nonresonant		$(3.3 \pm 1.0) \times 10^{-5}$		2522
$K_S^0 K_S^0 K_S^0$		$(6.0 \pm 0.5) \times 10^{-6}$	S=1.1	2521
$f_0(980)K^0$, $f_0 \to K_S^0 K_S^0$		$(2.7 \pm 1.8) \times 10^{-6}$		–
$f_0(1710)K^0$, $f_0 \to K_S^0 K_S^0$		$(5.0 {}^{+5.0}_{-2.6}) \times 10^{-7}$		–
$f_2(2010)K^0$, $f_2 \to K_S^0 K_S^0$		$(5 \pm 6) \times 10^{-7}$		–
$K_S^0 K_S^0 K_S^0$ nonresonant		$(1.33 \pm 0.31) \times 10^{-5}$		2521
$K_S^0 K_S^0 K_L^0$		$< 1.6 \times 10^{-5}$	CL=90%	2521
$K^*(892)^0 K^+K^-$		$(2.75 \pm 0.26) \times 10^{-5}$		2467
$K^*(892)^0\phi$		$(1.00 \pm 0.05) \times 10^{-5}$		2460
$K^+K^-\pi^+\pi^-$ nonresonant		$< 7.17 \times 10^{-5}$	CL=90%	2559
$K^*(892)^0 K^-\pi^+$		$(4.5 \pm 1.3) \times 10^{-6}$		2524
$K^*(892)^0\overline{K}^*(892)^0$		$(8 \pm 5) \times 10^{-7}$	S=2.2	2485
$K^+K^+\pi^-\pi^-$ nonresonant		$< 6.0 \times 10^{-6}$	CL=90%	2559
$K^*(892)^0 K^+\pi^-$		$< 2.2 \times 10^{-6}$	CL=90%	2524
$K^*(892)^0 K^*(892)^0$		$< 2 \times 10^{-7}$	CL=90%	2485
$K^*(892)^+ K^*(892)^-$		$< 2.0 \times 10^{-6}$	CL=90%	2485

$K_1(1400)^0\phi$		$<$ 5.0	$\times 10^{-3}$	CL=90%	2339
$\phi(K\pi)^{*0}_0$		(4.3 $\pm$ 0.4)	$\times 10^{-6}$		–
$\phi(K\pi)^{*0}_0$ ($1.60<m_{K\pi}<2.15$)	[ddaa]	$<$ 1.7	$\times 10^{-6}$	CL=90%	–
$K^*_0(1430)^0 K^-\pi^+$		$<$ 3.18	$\times 10^{-5}$	CL=90%	2403
$K^*_0(1430)^0\overline{K}^*(892)^0$		$<$ 3.3	$\times 10^{-6}$	CL=90%	2360
$K^*_0(1430)^0\overline{K}^*_0(1430)^0$		$<$ 8.4	$\times 10^{-6}$	CL=90%	2222
$K^*_0(1430)^0\phi$		(3.9 $\pm$ 0.8)	$\times 10^{-6}$		2333
$K^*_0(1430)^0 K^*(892)^0$		$<$ 1.7	$\times 10^{-6}$	CL=90%	2360
$K^*_0(1430)^0 K^*_0(1430)^0$		$<$ 4.7	$\times 10^{-6}$	CL=90%	2222
$K^*(1680)^0\phi$		$<$ 3.5	$\times 10^{-6}$	CL=90%	2238
$K^*(1780)^0\phi$		$<$ 2.7	$\times 10^{-6}$	CL=90%	–
$K^*(2045)^0\phi$		$<$ 1.53	$\times 10^{-5}$	CL=90%	–
$K^*_2(1430)^0\rho^0$		$<$ 1.1	$\times 10^{-3}$	CL=90%	2381
$K^*_2(1430)^0\phi$		(6.8 $\pm$ 0.9)	$\times 10^{-6}$	S=1.2	2333
$K^0\phi\phi$		(4.5 $\pm$ 0.9)	$\times 10^{-6}$		2305
$\eta'\eta' K^0$		$<$ 3.1	$\times 10^{-5}$	CL=90%	2337
$\eta K^0\gamma$		(7.6 $\pm$ 1.8)	$\times 10^{-6}$		2587
$\eta' K^0\gamma$		$<$ 6.4	$\times 10^{-6}$	CL=90%	2528
$K^0\phi\gamma$		(2.7 $\pm$ 0.7)	$\times 10^{-6}$		2516
$K^+\pi^-\gamma$		(4.6 $\pm$ 1.4)	$\times 10^{-6}$		2615
$K^*(892)^0\gamma$		(4.18 $\pm$ 0.25)	$\times 10^{-5}$	S=2.1	2565
$K^*(1410)\gamma$		$<$ 1.3	$\times 10^{-4}$	CL=90%	2449
$K^+\pi^-\gamma$ nonresonant		$<$ 2.6	$\times 10^{-6}$	CL=90%	2615
$K^*(892)^0 X(214)$, $X\to\mu^+\mu^-$	[eeaa]	$<$ 2.26	$\times 10^{-8}$	CL=90%	–
$K^0\pi^+\pi^-\gamma$		(1.99 $\pm$ 0.18)	$\times 10^{-5}$		2609
$K^+\pi^-\pi^0\gamma$		(4.1 $\pm$ 0.4)	$\times 10^{-5}$		2609
$K_1(1270)^0\gamma$		$<$ 5.8	$\times 10^{-5}$	CL=90%	2486
$K_1(1400)^0\gamma$		$<$ 1.2	$\times 10^{-5}$	CL=90%	2454
$K^*_2(1430)^0\gamma$		(1.24 $\pm$ 0.24)	$\times 10^{-5}$		2447
$K^*(1680)^0\gamma$		$<$ 2.0	$\times 10^{-3}$	CL=90%	2360
$K^*_3(1780)^0\gamma$		$<$ 8.3	$\times 10^{-5}$	CL=90%	2341
$K^*_4(2045)^0\gamma$		$<$ 4.3	$\times 10^{-3}$	CL=90%	2244

Light unflavored meson modes

$\rho^0\gamma$		(8.6 $\pm$ 1.5)	$\times 10^{-7}$		2583
$\rho^0 X(214)$, $X\to\mu^+\mu^-$	[eeaa]	$<$ 1.73	$\times 10^{-8}$	CL=90%	–
$\omega\gamma$		(4.4 $^{+1.8}_{-1.6}$)	$\times 10^{-7}$		2582
$\phi\gamma$		$<$ 1.0	$\times 10^{-7}$	CL=90%	2541
$\pi^+\pi^-$		(5.12 $\pm$ 0.19)	$\times 10^{-6}$		2636
$\pi^0\pi^0$		(1.59 $\pm$ 0.26)	$\times 10^{-6}$	S=1.4	2636
$\eta\pi^0$		(4.1 $\pm$ 1.7)	$\times 10^{-7}$		2610
$\eta\eta$		$<$ 1.0	$\times 10^{-6}$	CL=90%	2582
$\eta'\pi^0$		(1.2 $\pm$ 0.6)	$\times 10^{-6}$	S=1.7	2551
$\eta'\eta'$		$<$ 1.7	$\times 10^{-6}$	CL=90%	2460
$\eta'\eta$		$<$ 1.2	$\times 10^{-6}$	CL=90%	2523
$\eta'\rho^0$		$<$ 1.3	$\times 10^{-6}$	CL=90%	2492
$\eta' f_0(980)$, $f_0\to\pi^+\pi^-$		$<$ 9	$\times 10^{-7}$	CL=90%	2454
$\eta\rho^0$		$<$ 1.5	$\times 10^{-6}$	CL=90%	2553
$\eta f_0(980)$, $f_0\to\pi^+\pi^-$		$<$ 4	$\times 10^{-7}$	CL=90%	2516
$\omega\eta$		(9.4 $^{+4.0}_{-3.1}$)	$\times 10^{-7}$		2552
$\omega\eta'$		(1.0 $^{+0.5}_{-0.4}$)	$\times 10^{-6}$		2491
$\omega\rho^0$		$<$ 1.6	$\times 10^{-6}$	CL=90%	2522
$\omega f_0(980)$, $f_0\to\pi^+\pi^-$		$<$ 1.5	$\times 10^{-6}$	CL=90%	2485

$\omega\omega$		$(1.2 \pm 0.4) \times 10^{-6}$			2521
$\phi\pi^0$		$< 1.5 \times 10^{-7}$		CL=90%	2540
$\phi\eta$		$< 5 \times 10^{-7}$		CL=90%	2511
$\phi\eta'$		$< 5 \times 10^{-7}$		CL=90%	2448
$\phi\pi^+\pi^-$		$(1.8 \pm 0.5) \times 10^{-7}$			2533
$\quad\phi\rho^0$		$< 3.3 \times 10^{-7}$		CL=90%	2480
$\quad\phi f_0(980)$, $f_0 \to \pi^+\pi^-$		$< 3.8 \times 10^{-7}$		CL=90%	2441
$\phi\omega$		$< 7 \times 10^{-7}$		CL=90%	2479
$\phi\phi$		$< 2.8 \times 10^{-8}$		CL=90%	2435
$a_0(980)^\pm\pi^\mp$, $a_0^\pm \to \eta\pi^\pm$		$< 3.1 \times 10^{-6}$		CL=90%	–
$a_0(1450)^\pm\pi^\mp$, $a_0^\pm \to \eta\pi^\pm$		$< 2.3 \times 10^{-6}$		CL=90%	–
$\pi^+\pi^-\pi^0$		$< 7.2 \times 10^{-4}$		CL=90%	2631
$\quad\rho^0\pi^0$		$(2.0 \pm 0.5) \times 10^{-6}$			2581
$\quad\rho^\mp\pi^\pm$	[hh]	$(2.30 \pm 0.23) \times 10^{-5}$			2581
$\pi^+\pi^-\pi^+\pi^-$		$< 1.12 \times 10^{-5}$		CL=90%	2621
$\quad\rho^0\pi^+\pi^-$		$< 8.8 \times 10^{-6}$		CL=90%	2575
$\quad\rho^0\rho^0$		$(9.6 \pm 1.5) \times 10^{-7}$			2523
$\quad\quad f_0(980)\pi^+\pi^-$, $f_0 \to \pi^+\pi^-$		$< 3.0 \times 10^{-6}$		CL=90%	–
$\quad\rho^0 f_0(980)$, $f_0 \to \pi^+\pi^-$		$(7.8 \pm 2.5) \times 10^{-7}$			2486
$\quad f_0(980) f_0(980)$, $f_0 \to \pi^+\pi^-$, $f_0 \to \pi^+\pi^-$		$< 1.9 \times 10^{-7}$		CL=90%	2447
$f_0(980) f_0(980)$, $f_0 \to \pi^+\pi^-$, $f_0 \to K^+K^-$		$< 2.3 \times 10^{-7}$		CL=90%	2447
$\quad a_1(1260)^\mp\pi^\pm$	[hh]	$(2.6 \pm 0.5) \times 10^{-5}$		S=1.9	2494
$\quad a_2(1320)^\mp\pi^\pm$	[hh]	$< 6.3 \times 10^{-6}$		CL=90%	2473
$\pi^+\pi^-\pi^0\pi^0$		$< 3.1 \times 10^{-3}$		CL=90%	2622
$\quad\rho^+\rho^-$		$(2.77 \pm 0.19) \times 10^{-5}$			2523
$\quad a_1(1260)^0\pi^0$		$< 1.1 \times 10^{-3}$		CL=90%	2495
$\quad\omega\pi^0$		$< 5 \times 10^{-7}$		CL=90%	2580
$\pi^+\pi^+\pi^-\pi^-\pi^0$		$< 9.0 \times 10^{-3}$		CL=90%	2609
$\quad a_1(1260)^+\rho^-$		$< 6.1 \times 10^{-5}$		CL=90%	2433
$\quad a_1(1260)^0\rho^0$		$< 2.4 \times 10^{-3}$		CL=90%	2433
$\quad b_1^\mp\pi^\pm$, $b_1^\mp \to \omega\pi^\mp$		$(1.09 \pm 0.15) \times 10^{-5}$			–
$b_1^0\pi^0$, $b_1^0 \to \omega\pi^0$		$< 1.9 \times 10^{-6}$		CL=90%	–
$b_1^-\rho^+$, $b_1^- \to \omega\pi^-$		$< 1.4 \times 10^{-6}$		CL=90%	–
$b_1^0\rho^0$, $b_1^0 \to \omega\pi^0$		$< 3.4 \times 10^{-6}$		CL=90%	–
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-$		$< 3.0 \times 10^{-3}$		CL=90%	2592
$\quad a_1(1260)^+ a_1(1260)^-$, $a_1^+ \to 2\pi^+\pi^-$, $a_1^- \to 2\pi^-\pi^+$		$(1.18 \pm 0.31) \times 10^{-5}$			2336
$\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^0$		< 1.1 %		CL=90%	2572

Baryon modes

$p\overline{p}$		$(1.25 \pm 0.32) \times 10^{-8}$			2467
$p\overline{p}\pi^+\pi^-$		$(2.87 \pm 0.19) \times 10^{-6}$			2406
$p\overline{p}K^+\pi^-$		$(6.3 \pm 0.5) \times 10^{-6}$			2306
$p\overline{p}K^0$		$(2.66 \pm 0.32) \times 10^{-6}$			2347
$\quad\Theta(1540)^+\overline{p}$, $\Theta^+ \to pK_S^0$	[ffaa]	$< 5 \times 10^{-8}$		CL=90%	2318
$\quad f_J(2220)K^0$, $f_J \to p\overline{p}$		$< 4.5 \times 10^{-7}$		CL=90%	2135
$p\overline{p}K^*(892)^0$		$(1.24^{+0.28}_{-0.25}) \times 10^{-6}$			2216
$\quad f_J(2220)K_0^*$, $f_J \to p\overline{p}$		$< 1.5 \times 10^{-7}$		CL=90%	–
$p\overline{p}K^+K^-$		$(1.21 \pm 0.32) \times 10^{-7}$			2179
$p\overline{\Lambda}\pi^-$		$(3.14 \pm 0.29) \times 10^{-6}$			2401
$p\overline{\Lambda}\pi^-\gamma$		$< 6.5 \times 10^{-7}$		CL=90%	2401
$p\overline{\Sigma}(1385)^-$		$< 2.6 \times 10^{-7}$		CL=90%	2363

$\Delta^0 \overline{\Lambda}$	<	9.3	$\times 10^{-7}$	CL=90%	2364
$p \overline{\Lambda} K^-$	<	8.2	$\times 10^{-7}$	CL=90%	2308
$p \overline{\Lambda} D^-$	(	2.5 $\pm$ 0.4	) $\times 10^{-5}$		1765
$p \overline{\Lambda} D^{*-}$	(	3.4 $\pm$ 0.8	) $\times 10^{-5}$		1685
$p \overline{\Sigma}^0 \pi^-$	<	3.8	$\times 10^{-6}$	CL=90%	2383
$\overline{\Lambda} \Lambda$	<	3.2	$\times 10^{-7}$	CL=90%	2392
$\overline{\Lambda} \Lambda K^0$	(	4.8 $^{+1.0}_{-0.9}$	) $\times 10^{-6}$		2250
$\overline{\Lambda} \Lambda K^{*0}$	(	2.5 $^{+0.9}_{-0.8}$	) $\times 10^{-6}$		2098
$\overline{\Lambda} \Lambda D^0$	(	1.00 $^{+0.30}_{-0.26}$	) $\times 10^{-5}$		1661
$D^0 \Sigma^0 \overline{\Lambda}$ + c.c.	<	3.1	$\times 10^{-5}$	CL=90%	1611
$\Delta^0 \overline{\Delta}^0$	<	1.5	$\times 10^{-3}$	CL=90%	2335
$\Delta^{++} \overline{\Delta}^{--}$	<	1.1	$\times 10^{-4}$	CL=90%	2335
$\overline{D}^0 p \overline{p}$	(	1.04 $\pm$ 0.07	) $\times 10^{-4}$		1863
$D_s^- \overline{\Lambda} p$	(	2.8 $\pm$ 0.9	) $\times 10^{-5}$		1710
$\overline{D}^*(2007)^0 p \overline{p}$	(	9.9 $\pm$ 1.1	) $\times 10^{-5}$		1788
$D^*(2010)^- p \overline{n}$	(	1.4 $\pm$ 0.4	) $\times 10^{-3}$		1785
$D^- p \overline{p} \pi^+$	(	3.32 $\pm$ 0.31	) $\times 10^{-4}$		1786
$D^*(2010)^- p \overline{p} \pi^+$	(	4.7 $\pm$ 0.5	) $\times 10^{-4}$	S=1.2	1708
$\overline{D}^0 p \overline{p} \pi^+ \pi^-$	(	3.0 $\pm$ 0.5	) $\times 10^{-4}$		1708
$\overline{D}^{*0} p \overline{p} \pi^+ \pi^-$	(	1.9 $\pm$ 0.5	) $\times 10^{-4}$		1623
$\Theta_c \overline{p} \pi^+$, $\Theta_c \to D^- p$	<	9	$\times 10^{-6}$	CL=90%	–
$\Theta_c \overline{p} \pi^+$, $\Theta_c \to D^{*-} p$	<	1.4	$\times 10^{-5}$	CL=90%	–
$\overline{\Sigma}_c^{--} \Delta^{++}$	<	8	$\times 10^{-4}$	CL=90%	1839
$\overline{\Lambda}_c^- p \pi^+ \pi^-$	(	1.03 $\pm$ 0.14	) $\times 10^{-3}$	S=1.3	1934
$\overline{\Lambda}_c^- p$	(	1.55 $\pm$ 0.18	) $\times 10^{-5}$		2021
$\overline{\Lambda}_c^- p \pi^0$	(	1.56 $\pm$ 0.19	) $\times 10^{-4}$		1982
$\Sigma_c(2455)^- p$	<	2.4	$\times 10^{-5}$		–
$\overline{\Lambda}_c^- p \pi^+ \pi^- \pi^0$	<	5.07	$\times 10^{-3}$	CL=90%	1882
$\overline{\Lambda}_c^- p \pi^+ \pi^- \pi^+ \pi^-$	<	2.74	$\times 10^{-3}$	CL=90%	1821
$\overline{\Lambda}_c^- p \pi^+ \pi^-$ (nonresonant)	(	5.5 $\pm$ 1.0	) $\times 10^{-4}$	S=1.3	1934
$\overline{\Sigma}_c(2520)^{--} p \pi^+$	(	1.03 $\pm$ 0.18	) $\times 10^{-4}$		1860
$\overline{\Sigma}_c(2520)^0 p \pi^-$	<	3.1	$\times 10^{-5}$	CL=90%	1860
$\overline{\Sigma}_c(2455)^0 p \pi^-$	(	1.08 $\pm$ 0.16	) $\times 10^{-4}$		1895
$\overline{\Sigma}_c(2455)^0 N^0$, $N^0 \to p \pi^-$	(	6.4 $\pm$ 1.7	) $\times 10^{-5}$		–
$\overline{\Sigma}_c(2455)^{--} p \pi^+$	(	1.85 $\pm$ 0.24	) $\times 10^{-4}$		1895
$\Lambda_c^- p K^+ \pi^-$	(	3.5 $\pm$ 0.7	) $\times 10^{-5}$		–
$\overline{\Sigma}_c(2455)^{--} p K^+$, $\overline{\Sigma}_c^{--} \to \overline{\Lambda}_c^- \pi^-$	(	8.9 $\pm$ 2.6	) $\times 10^{-6}$		1754
$\Lambda_c^- p K^*(892)^0$	<	2.42	$\times 10^{-5}$	CL=90%	–
$\Lambda_c^- p K^+ K^-$	(	2.0 $\pm$ 0.4	) $\times 10^{-5}$		–
$\Lambda_c^- p \phi$	<	1.0	$\times 10^{-5}$	CL=90%	–
$\Lambda_c^- p \overline{p} p$	<	2.8	$\times 10^{-6}$		–
$\overline{\Lambda}_c^- \Lambda K^+$	(	4.7 $\pm$ 1.1	) $\times 10^{-5}$		1767
$\overline{\Lambda}_c^- \Lambda_c^+$	<	1.6	$\times 10^{-5}$	CL=95%	1319
$\overline{\Lambda}_c(2593)^-$ / $\overline{\Lambda}_c(2625)^- p$	<	1.1	$\times 10^{-4}$	CL=90%	–
$\Xi_c^- \Lambda_c^+$, $\Xi_c^- \to \Xi^+ \pi^- \pi^-$	(	1.8 $\pm$ 1.8	) $\times 10^{-5}$	S=2.2	1147
$\Lambda_c^+ \Lambda_c^- K^0$	(	4.3 $\pm$ 2.3	) $\times 10^{-4}$		–

Lepton Family number (*LF*) or Lepton number (*L*) or Baryon number (*B*) violating modes, or/and $\Delta B = 1$ weak neutral current (*B1*) modes

$\gamma\gamma$	*B1*		< 3.2	$\times 10^{-7}$	CL=90%	2640
$e^+ e^-$	*B1*		< 8.3	$\times 10^{-8}$	CL=90%	2640
$e^+ e^- \gamma$	*B1*		< 1.2	$\times 10^{-7}$	CL=90%	2640
$\mu^+ \mu^-$	*B1*		$(1.6 \ ^{+1.6}_{-1.4}$	$) \times 10^{-10}$	S=1.9	2638
$\mu^+ \mu^- \gamma$	*B1*		< 1.6	$\times 10^{-7}$	CL=90%	2638
$\mu^+ \mu^- \mu^+ \mu^-$	*B1*		< 6.9	$\times 10^{-10}$	CL=95%	2629
SP, $S \to \mu^+ \mu^-$, $P \to \mu^+ \mu^-$	*B1*	[*ggaa*]	< 6.0	$\times 10^{-10}$	CL=95%	–
$\tau^+ \tau^-$	*B1*		< 2.1	$\times 10^{-3}$	CL=95%	1952
$\pi^0 \ell^+ \ell^-$	*B1*		< 5.3	$\times 10^{-8}$	CL=90%	2638
$\pi^0 e^+ e^-$	*B1*		< 8.4	$\times 10^{-8}$	CL=90%	2638
$\pi^0 \mu^+ \mu^-$	*B1*		< 6.9	$\times 10^{-8}$	CL=90%	2634
$\eta \ell^+ \ell^-$	*B1*		< 6.4	$\times 10^{-8}$	CL=90%	2611
$\eta e^+ e^-$	*B1*		< 1.08	$\times 10^{-7}$	CL=90%	2611
$\eta \mu^+ \mu^-$	*B1*		< 1.12	$\times 10^{-7}$	CL=90%	2607
$\pi^0 \nu \overline{\nu}$	*B1*		< 9	$\times 10^{-6}$	CL=90%	2638
$K^0 \ell^+ \ell^-$	*B1*	[*sss*]	$(3.1 \ ^{+0.8}_{-0.7}$	$) \times 10^{-7}$		2616
$K^0 e^+ e^-$	*B1*		$(1.6 \ ^{+1.0}_{-0.8}$	$) \times 10^{-7}$		2616
$K^0 \mu^+ \mu^-$	*B1*		$(3.39 \pm 0.34$	$) \times 10^{-7}$		2612
$K^0 \nu \overline{\nu}$	*B1*		< 2.6	$\times 10^{-5}$	CL=90%	2616
$\rho^0 \nu \overline{\nu}$	*B1*		< 4.0	$\times 10^{-5}$	CL=90%	2583
$K^*(892)^0 \ell^+ \ell^-$	*B1*	[*sss*]	$(9.9 \ ^{+1.2}_{-1.1}$	$) \times 10^{-7}$		2565
$K^*(892)^0 e^+ e^-$	*B1*		$(1.03 \ ^{+0.19}_{-0.17}$	$) \times 10^{-6}$		2565
$K^*(892)^0 \mu^+ \mu^-$	*B1*		$(9.4 \pm 0.5$	$) \times 10^{-7}$		2560
$\pi^+ \pi^- \mu^+ \mu^-$	*B1*		$(2.1 \pm 0.5$	$) \times 10^{-8}$		2626
$K^*(892)^0 \nu \overline{\nu}$	*B1*		< 1.8	$\times 10^{-5}$	CL=90%	2565
invisible	*B1*		< 2.4	$\times 10^{-5}$	CL=90%	–
$\nu \overline{\nu} \gamma$	*B1*		< 1.7	$\times 10^{-5}$	CL=90%	2640
$\phi \nu \overline{\nu}$	*B1*		< 1.27	$\times 10^{-4}$	CL=90%	2541
$e^\pm \mu^\mp$	*LF*	[*hh*]	< 2.8	$\times 10^{-9}$	CL=90%	2639
$\pi^0 e^\pm \mu^\mp$	*LF*		< 1.4	$\times 10^{-7}$	CL=90%	2637
$K^0 e^\pm \mu^\mp$	*LF*		< 2.7	$\times 10^{-7}$	CL=90%	2615
$K^*(892)^0 e^+ \mu^-$	*LF*		< 5.3	$\times 10^{-7}$	CL=90%	2563
$K^*(892)^0 e^- \mu^+$	*LF*		< 3.4	$\times 10^{-7}$	CL=90%	2563
$K^*(892)^0 e^\pm \mu^\mp$	*LF*		< 5.8	$\times 10^{-7}$	CL=90%	2563
$e^\pm \tau^\mp$	*LF*	[*hh*]	< 2.8	$\times 10^{-5}$	CL=90%	2341
$\mu^\pm \tau^\mp$	*LF*	[*hh*]	< 2.2	$\times 10^{-5}$	CL=90%	2339
$\Lambda_c^+ \mu^-$	*L,B*		< 1.4	$\times 10^{-6}$	CL=90%	2143
$\Lambda_c^+ e^-$	*L,B*		< 4	$\times 10^{-6}$	CL=90%	2145

$B^\pm/B^0$ ADMIXTURE

CP violation

$A_{CP}(B \to K^*(892)\gamma) = -0.003 \pm 0.011$

$A_{CP}(b \to s\gamma) = 0.015 \pm 0.020$

$A_{CP}(b \to (s+d)\gamma) = 0.010 \pm 0.031$

$A_{CP}(B \to X_s \ell^+ \ell^-) = 0.04 \pm 0.11$

$A_{CP}(B \to X_s \ell^+ \ell^-)\ (1.0 < q^2 < 6.0\ \mathrm{GeV}^2/c^4) = -0.06 \pm 0.22$

$A_{CP}(B \to X_s \ell^+ \ell^-)$ ($10.1 < q^2 < 12.9$ or $q^2 > 14.2$ GeV^2/c^4) = 0.19 ± 0.18
$A_{CP}(B \to K^* e^+ e^-) = -0.18 \pm 0.15$
$A_{CP}(B \to K^* \mu^+ \mu^-) = -0.03 \pm 0.13$
$A_{CP}(B \to K^* \ell^+ \ell^-) = -0.04 \pm 0.07$
$A_{CP}(B \to \eta \text{anything}) = -0.13^{+0.04}_{-0.05}$
$\Delta A_{CP}(X_s \gamma) = A_{CP}(B^\pm \to X_s \gamma) - A_{CP}(B^0 \to X_s \gamma) = 0.05 \pm 0.04$
$\Delta A_{CP}(B \to K^* \gamma) = A_{CP}(B^+ \to K^{*+} \gamma) - A_{CP}(B^0 \to K^{*0} \gamma) = 0.024 \pm 0.028$
$\overline{A}_{CP}(B \to K^* \gamma) = (A_{CP}(B^+ \to K^{*+} \gamma) + A_{CP}(B^0 \to K^{*0} \gamma))/2 = -0.001 \pm 0.014$

The branching fraction measurements are for an admixture of B mesons at the $\Upsilon(4S)$. The values quoted assume that $B(\Upsilon(4S) \to B\overline{B}) = 100\%$.

For inclusive branching fractions, *e.g.*, $B \to D^\pm$ *anything*, the treatment of multiple D's in the final state must be defined. One possibility would be to count the number of events with one-or-more D's and divide by the total number of B's. Another possibility would be to count the total number of D's and divide by the total number of B's, which is the definition of average multiplicity. The two definitions are identical if only one D is allowed in the final state.

Even though the "one-or-more" definition seems sensible, for practical reasons inclusive branching fractions are almost always measured using the multiplicity definition. For heavy final state particles, authors call their results inclusive branching fractions while for light particles some authors call their results multiplicities. In the B sections, we list all results as inclusive branching fractions, adopting a multiplicity definition. This means that inclusive branching fractions can exceed 100% and that inclusive partial widths can exceed total widths, just as inclusive cross sections can exceed total cross section.

$\overline{B}$ modes are charge conjugates of the modes below. Reactions indicate the weak decay vertex and do not include mixing.

***B* DECAY MODES**		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Semileptonic and leptonic modes				
$\ell^+ \nu_\ell$ anything	[sss,hhaa]	(10.86 ± 0.16) %		–
$D^- \ell^+ \nu_\ell$ anything	[sss]	(2.8 ± 0.9) %		–
$\overline{D}^0 \ell^+ \nu_\ell$ anything	[sss]	(7.3 ± 1.5) %		–
$\overline{D} \ell^+ \nu_\ell$		(2.42 ± 0.12) %		2310
$D^{*-} \ell^+ \nu_\ell$ anything	[iiaa]	(6.7 ± 1.3) $\times 10^{-3}$		–
$D^* \ell^+ \nu_\ell$	[jjaa]	(4.95 ± 0.11) %		2257
$\overline{D}^{**} \ell^+ \nu_\ell$	[sss,kkaa]	(2.7 ± 0.7) %		–
$\overline{D}_1(2420) \ell^+ \nu_\ell$ anything		(3.8 ± 1.3) $\times 10^{-3}$	S=2.4	–
$D \pi \ell^+ \nu_\ell$ anything + $D^* \pi \ell^+ \nu_\ell$ anything		(2.6 ± 0.5) %	S=1.5	–
$D \pi \ell^+ \nu_\ell$ anything		(1.5 ± 0.6) %		–
$D^* \pi \ell^+ \nu_\ell$ anything		(1.9 ± 0.4) %		–
$\overline{D}_2^*(2460) \ell^+ \nu_\ell$ anything		(4.4 ± 1.6) $\times 10^{-3}$		–
$D^{*-} \pi^+ \ell^+ \nu_\ell$ anything		(1.00 ± 0.34) %		–
$\overline{D} \pi^+ \pi^- \ell^+ \nu_\ell$		(1.62 ± 0.32) $\times 10^{-3}$		2301
$\overline{D}^* \pi^+ \pi^- \ell^+ \nu_\ell$		(9.4 ± 3.2) $\times 10^{-4}$		2247
$D_s^- \ell^+ \nu_\ell$ anything	[sss]	< 7 $\times 10^{-3}$	CL=90%	–
$D_s^- \ell^+ \nu_\ell K^+$ anything	[sss]	< 5 $\times 10^{-3}$	CL=90%	–
$D_s^- \ell^+ \nu_\ell K^0$ anything	[sss]	< 7 $\times 10^{-3}$	CL=90%	–
$X_c \ell^+ \nu_\ell$		(10.65 ± 0.16) %		–

$X_u \ell^+ \nu_\ell$		$(2.13 \pm 0.31) \times 10^{-3}$		–
$K^+ \ell^+ \nu_\ell$ anything	[sss]	(6.3 ± 0.6) %		–
$K^- \ell^+ \nu_\ell$ anything	[sss]	$(10 \pm 4) \times 10^{-3}$		–
$K^0 / \overline{K}^0 \ell^+ \nu_\ell$ anything	[sss]	(4.6 ± 0.5) %		–
$\overline{D} \tau^+ \nu_\tau$		$(9.9 \pm 1.2) \times 10^{-3}$		1911
$D^* \tau^+ \nu_\tau$		(1.50 ± 0.08) %		1838
D, D^*, or D_s modes				
$D^\pm$ anything		(24.1 ± 1.4) %		–
$D^0 / \overline{D}^0$ anything		(62.4 ± 2.9) %	S=1.3	–
$D^*(2010)^\pm$ anything		(22.5 ± 1.5) %		–
$D^*(2007)^0$ anything		(26.0 ± 2.7) %		–
$D_s^\pm$ anything	[hh]	(8.3 ± 0.8) %		–
$D_s^{*\pm}$ anything		(6.3 ± 1.0) %		–
$D_s^{*\pm} \overline{D}^{(*)}$		(3.4 ± 0.6) %		–
$D^{(*)} \overline{D}^{(*)} K^0 + D^{(*)} \overline{D}^{(*)} K^\pm$	[hh,llaa]	$(7.1 {}^{+2.7}_{-1.7})$ %		–
$b \to c \overline{c} s$		(22 ± 4) %		–
$D_s{}^{(*)} \overline{D}^{(*)}$	[hh,llaa]	(3.9 ± 0.4) %		–
$D^* D^*(2010)^\pm$	[hh]	$< 5.9 \times 10^{-3}$	CL=90%	1711
$D D^*(2010)^\pm + D^* D^\pm$	[hh]	$< 5.5 \times 10^{-3}$	CL=90%	–
$D D^\pm$	[hh]	$< 3.1 \times 10^{-3}$	CL=90%	1866
$D_s{}^{(*)\pm} \overline{D}^{(*)} X(n\pi^\pm)$	[hh,llaa]	$(9 {}^{+5}_{-4})$ %		–
$D^*(2010)\gamma$		$< 1.1 \times 10^{-3}$	CL=90%	2257
$D_s^+ \pi^-$, $D_s^{*+} \pi^-$, $D_s^+ \rho^-$, $D_s^{*+} \rho^-$, $D_s^+ \pi^0$, $D_s^{*+} \pi^0$, $D_s^+ \eta$, $D_s^{*+} \eta$, $D_s^+ \rho^0$, $D_s^{*+} \rho^0$, $D_s^+ \omega$, $D_s^{*+} \omega$	[hh]	$< 4 \times 10^{-4}$	CL=90%	–
$D_{s1}(2536)^+$ anything		$< 9.5 \times 10^{-3}$	CL=90%	–
Charmonium modes				
$J/\psi(1S)$ anything		(1.094 ± 0.032) %	S=1.1	–
$J/\psi(1S)$ (direct) anything		$(7.8 \pm 0.4) \times 10^{-3}$	S=1.1	–
$\psi(2S)$ anything		$(3.07 \pm 0.21) \times 10^{-3}$		–
$\chi_{c1}(1P)$ anything		$(3.55 \pm 0.27) \times 10^{-3}$	S=1.3	–
$\chi_{c1}(1P)$ (direct) anything		$(3.08 \pm 0.19) \times 10^{-3}$		–
$\chi_{c2}(1P)$ anything		$(10.0 \pm 1.7) \times 10^{-4}$	S=1.6	–
$\chi_{c2}(1P)$ (direct) anything		$(7.5 \pm 1.1) \times 10^{-4}$		–
$\eta_c(1S)$ anything		$< 9 \times 10^{-3}$	CL=90%	–
$K \chi_{c1}(3872)$, $\chi_{c1} \to D^0 \overline{D}^0 \pi^0$		$(1.2 \pm 0.4) \times 10^{-4}$		1141
$K \chi_{c1}(3872)$, $\chi_{c1} \to D^{*0} D^0$		$(8.0 \pm 2.2) \times 10^{-5}$		1141
$K X(3940)$, $X \to D^{*0} D^0$		$< 6.7 \times 10^{-5}$	CL=90%	1084
$K X(3915)$, $X \to \omega J/\psi$	[nnaa]	$(7.1 \pm 3.4) \times 10^{-5}$		1103
K or K^* modes				
$K^\pm$ anything	[hh]	(78.9 ± 2.5) %		–
K^+ anything		(66 ± 5) %		–
K^- anything		(13 ± 4) %		–
$K^0 / \overline{K}^0$ anything	[hh]	(64 ± 4) %		–
$K^*(892)^\pm$ anything		(18 ± 6) %		–
$K^*(892)^0 / \overline{K}^*(892)^0$ anything	[hh]	(14.6 ± 2.6) %		–
$K^*(892)\gamma$		$(4.2 \pm 0.6) \times 10^{-5}$		2565
$\eta K \gamma$		$(8.5 {}^{+1.8}_{-1.6}) \times 10^{-6}$		2588

$K_1(1400)\gamma$		$< 1.27 \times 10^{-4}$	CL=90%	2454
$K_2^*(1430)\gamma$		$(1.7 {}^{+0.6}_{-0.5}) \times 10^{-5}$		2447
$K_2(1770)\gamma$		$< 1.2 \times 10^{-3}$	CL=90%	2342
$K_3^*(1780)\gamma$		$< 3.7 \times 10^{-5}$	CL=90%	2341
$K_4^*(2045)\gamma$		$< 1.0 \times 10^{-3}$	CL=90%	2244
$K\eta'(958)$		$(8.3 \pm 1.1) \times 10^{-5}$		2528
$K^*(892)\eta'(958)$		$(4.1 \pm 1.1) \times 10^{-6}$		2472
$K\eta$		$< 5.2 \times 10^{-6}$	CL=90%	2588
$K^*(892)\eta$		$(1.8 \pm 0.5) \times 10^{-5}$		2534
$K\phi\phi$		$(2.3 \pm 0.9) \times 10^{-6}$		2306
$\overline{b} \to \overline{s}\gamma$		$(3.49 \pm 0.19) \times 10^{-4}$		–
$\overline{b} \to \overline{d}\gamma$		$(9.2 \pm 3.0) \times 10^{-6}$		–
$\overline{b} \to \overline{s}$ gluon		< 6.8 %	CL=90%	–
η anything		$(2.6 {}^{+0.5}_{-0.8}) \times 10^{-4}$		–
η' anything		$(4.2 \pm 0.9) \times 10^{-4}$		–
K^+ gluon (charmless)		$< 1.87 \times 10^{-4}$	CL=90%	–
K^0 gluon (charmless)		$(1.9 \pm 0.7) \times 10^{-4}$		–
Light unflavored meson modes				
$\rho\gamma$		$(1.39 \pm 0.25) \times 10^{-6}$	S=1.2	2583
$\rho/\omega\gamma$		$(1.30 \pm 0.23) \times 10^{-6}$	S=1.2	–
$\pi^{\pm}$ anything	[hh,ooaa]	(358 ± 7) %		–
π^0 anything		(235 ± 11) %		–
η anything		(17.6 ± 1.6) %		–
ρ^0 anything		(21 ± 5) %		–
ω anything		< 81 %	CL=90%	–
ϕ anything		(3.43 ± 0.12) %		–
$\phi K^*(892)$		$< 2.2 \times 10^{-5}$	CL=90%	2460
π^+ gluon (charmless)		$(3.7 \pm 0.8) \times 10^{-4}$		–
Baryon modes				
$\Lambda_c^+ / \overline{\Lambda}_c^-$ anything		(3.6 ± 0.4) %		–
Λ_c^+ anything		< 1.3 %	CL=90%	–
$\overline{\Lambda}_c^-$ anything		< 7 %	CL=90%	–
$\overline{\Lambda}_c^- \ell^+$ anything		$< 9 \times 10^{-4}$	CL=90%	–
$\overline{\Lambda}_c^- e^+$ anything		$< 1.8 \times 10^{-3}$	CL=90%	–
$\overline{\Lambda}_c^- \mu^+$ anything		$< - 1.4 \times 10^{-3}$	CL=90%	–
$\overline{\Lambda}_c^- p$ anything		(2.06 ± 0.33) %		–
$\overline{\Lambda}_c^- p e^+ \nu_e$		$< 8 \times 10^{-4}$	CL=90%	2021
$\overline{\Sigma}_c^{--}$ anything		$(3.4 \pm 1.7) \times 10^{-3}$		–
$\overline{\Sigma}_c^-$ anything		$< 8 \times 10^{-3}$	CL=90%	–
$\overline{\Sigma}_c^0$ anything		$(3.7 \pm 1.7) \times 10^{-3}$		–
$\overline{\Sigma}_c^0 N (N = p$ or $n)$		$< 1.2 \times 10^{-3}$	CL=90%	1938
Ξ_c^0 anything, $\Xi_c^0 \to \Xi^- \pi^+$		$(1.93 \pm 0.30) \times 10^{-4}$	S=1.1	–
Ξ_c^+, $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$		$(4.5 {}^{+1.3}_{-1.2}) \times 10^{-4}$		–
$p/\overline{p}$ anything	[hh]	(8.0 ± 0.4) %		–
$p/\overline{p}$ (direct) anything	[hh]	(5.5 ± 0.5) %		–
$\overline{p} e^+ \nu_e$ anything		$< 5.9 \times 10^{-4}$	CL=90%	–
$\Lambda/\overline{\Lambda}$ anything	[hh]	(4.0 ± 0.5) %		–
$\Xi^- / \overline{\Xi}^+$ anything	[hh]	$(2.7 \pm 0.6) \times 10^{-3}$		–
baryons anything		(6.8 ± 0.6) %		–

$p\overline{p}$ anything		(2.47 ± 0.23) %			–
$\Lambda\overline{p}/\overline{\Lambda}p$ anything	[hh]	(2.5 ± 0.4) %			–
$\Lambda\overline{\Lambda}$ anything		< 5	$\times 10^{-3}$	CL=90%	–

Lepton Family number (*LF*) violating modes or
$\Delta B = 1$ weak neutral current (*B1*) modes

$s e^+ e^-$	B1		(6.7 ± 1.7)	$\times 10^{-6}$	S=2.0	–
$s \mu^+ \mu^-$	B1		(4.3 ± 1.0)	$\times 10^{-6}$		–
$s \ell^+ \ell^-$	B1	[sss]	(5.8 ± 1.3)	$\times 10^{-6}$	S=1.8	–
$\pi \ell^+ \ell^-$	B1		< 5.9	$\times 10^{-8}$	CL=90%	2638
$\pi e^+ e^-$	B1		< 1.10	$\times 10^{-7}$	CL=90%	2638
$\pi \mu^+ \mu^-$	B1		< 5.0	$\times 10^{-8}$	CL=90%	2634
$K e^+ e^-$	B1		(4.4 ± 0.6)	$\times 10^{-7}$		2617
$K^*(892) e^+ e^-$	B1		(1.19 ± 0.20)	$\times 10^{-6}$	S=1.2	2565
$K \mu^+ \mu^-$	B1		(4.4 ± 0.4)	$\times 10^{-7}$		2612
$K^*(892) \mu^+ \mu^-$	B1		(1.06 ± 0.09)	$\times 10^{-6}$		2560
$K \ell^+ \ell^-$	B1		(4.8 ± 0.4)	$\times 10^{-7}$		2617
$K^*(892) \ell^+ \ell^-$	B1		(1.05 ± 0.10)	$\times 10^{-6}$		2565
$K \nu \overline{\nu}$	B1		< 1.6	$\times 10^{-5}$	CL=90%	2617
$K^* \nu \overline{\nu}$	B1		< 2.7	$\times 10^{-5}$	CL=90%	–
$\pi \nu \overline{\nu}$	B1		< 8	$\times 10^{-6}$	CL=90%	2638
$\rho \nu \overline{\nu}$	B1		< 2.8	$\times 10^{-5}$	CL=90%	2583
$s e^\pm \mu^\mp$	LF	[hh]	< 2.2	$\times 10^{-5}$	CL=90%	–
$\pi e^\pm \mu^\mp$	LF		< 9.2	$\times 10^{-8}$	CL=90%	2637
$\rho e^\pm \mu^\mp$	LF		< 3.2	$\times 10^{-6}$	CL=90%	2582
$K e^\pm \mu^\mp$	LF		< 3.8	$\times 10^{-8}$	CL=90%	2616
$K^*(892) e^\pm \mu^\mp$	LF		< 5.1	$\times 10^{-7}$	CL=90%	2563

See Particle Listings for 4 decay modes that have been seen / not seen.

$B^\pm/B^0/B^0_s/b$-baryon ADMIXTURE

These measurements are for an admixture of bottom particles at high energy (LHC, LEP, Tevatron, $Sp\overline{p}S$).

Mean life $\tau = (1.566 \pm 0.003) \times 10^{-12}$ s

Mean life $\tau = (1.72 \pm 0.10) \times 10^{-12}$ s Charged *b*-hadron admixture

Mean life $\tau = (1.58 \pm 0.14) \times 10^{-12}$ s Neutral *b*-hadron admixture

$\tau_{\text{charged } b-\text{hadron}} / \tau_{\text{neutral } b-\text{hadron}} = 1.09 \pm 0.13$

$|\Delta\tau_b| / \tau_{b,\overline{b}} = -0.001 \pm 0.014$

$\text{Re}(\epsilon_b)$ / $(1 + |\epsilon_b|^2) = (-1.3 \pm 0.4) \times 10^{-3}$

The branching fraction measurements are for an admixture of B mesons and baryons at energies above the $\Upsilon(4S)$. Only the highest energy results (LHC, LEP, Tevatron, $Sp\overline{p}S$) are used in the branching fraction averages. In the following, we assume that the production fractions are the same at the LHC, LEP, and at the Tevatron.

For inclusive branching fractions, *e.g.*, $B \rightarrow D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

The modes below are listed for a $\overline{b}$ initial state. b modes are their charge conjugates. Reactions indicate the weak decay vertex and do not include mixing.

$\overline{b}$ **DECAY MODES**		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)

PRODUCTION FRACTIONS

The production fractions for weakly decaying b-hadrons at high energy have been calculated from the best values of mean lives, mixing parameters, and branching fractions in this edition by the Heavy Flavor Averaging Group (HFLAV) as described in the note "B^0-$\overline{B}^0$ Mixing" in the B^0 Particle Listings. The production fractions in b-hadronic Z decay or $p\overline{p}$ collisions at the Tevatron are also listed at the end of the section. Values assume

$$B(\overline{b} \to B^+) = B(\overline{b} \to B^0)$$
$$B(\overline{b} \to B^+) + B(\overline{b} \to B^0) + B(\overline{b} \to B^0_s) + B(b \to b\text{-baryon}) = 100\%.$$

The correlation coefficients between production fractions are also reported:

$cor(B^0_s,\ b\text{-baryon}) = -0.259$
$cor(B^0_s,\ B^{\pm}{=}B^0) = -0.133$
$cor(b\text{-baryon},\ B^{\pm}{=}B^0) = -0.923.$

The notation for production fractions varies in the literature (f_d, d_{B^0}, $f(b \to \overline{B}^0)$, $\text{Br}(b \to \overline{B}^0)$). We use our own branching fraction notation here, $B(\overline{b} \to B^0)$.

Note these production fractions are b-hadronization fractions, not the conventional branching fractions of b-quark to a B-hadron, which may have considerable dependence on the initial and final state kinematic and production environment.

B^+		(40.5 ± 0.6) %		–
B^0		(40.5 ± 0.6) %		–
B^0_s		(10.1 ± 0.4) %		–
b-baryon		(8.9 ± 1.2) %		–

DECAY MODES

Semileptonic and leptonic modes

ν anything		(23.1 ± 1.5) %		–
$\ell^+ \nu_\ell$ anything	[sss]	(10.69 ± 0.22) %		–
$e^+ \nu_e$ anything		(10.86 ± 0.35) %		–
$\mu^+ \nu_\mu$ anything		$(10.95 {}^{+0.29}_{-0.25})$ %		–
$D^- \ell^+ \nu_\ell$ anything	[sss]	(2.30 ± 0.34) %	S=1.6	–
$D^- \pi^+ \ell^+ \nu_\ell$ anything		$(4.9 \pm 1.9) \times 10^{-3}$		–
$D^- \pi^- \ell^+ \nu_\ell$ anything		$(2.6 \pm 1.6) \times 10^{-3}$		–
$\overline{D}^0 \ell^+ \nu_\ell$ anything	[sss]	(6.83 ± 0.35) %		–
$\overline{D}^0 \pi^- \ell^+ \nu_\ell$ anything		(1.07 ± 0.27) %		–
$\overline{D}^0 \pi^+ \ell^+ \nu_\ell$ anything		$(2.3 \pm 1.6) \times 10^{-3}$		–
$D^{*-} \ell^+ \nu_\ell$ anything	[sss]	(2.75 ± 0.19) %		–
$D^{*-} \pi^- \ell^+ \nu_\ell$ anything		$(6 \pm 7) \times 10^{-4}$		–
$D^{*-} \pi^+ \ell^+ \nu_\ell$ anything		$(4.8 \pm 1.0) \times 10^{-3}$		–
$\overline{D}^0_j \ell^+ \nu_\ell$ anything $\times$ B($\overline{D}^0_j \to D^{*+} \pi^-$)	[sss,ppaa]	$(2.6 \pm 0.9) \times 10^{-3}$		–
$D^-_j \ell^+ \nu_\ell$ anything $\times$ B($D^-_j \to D^0 \pi^-$)	[sss,ppaa]	$(7.0 \pm 2.3) \times 10^{-3}$		–
$\overline{D}^*_2(2460)^0 \ell^+ \nu_\ell$ anything $\times$ B($\overline{D}^*_2(2460)^0 \to D^{*-} \pi^+$)		$< 1.4 \times 10^{-3}$	CL=90%	–

$D_2^*(2460)^- \ell^+ \nu_\ell$ anything $\times$ B($D_2^*(2460)^- \to D^0 \pi^-$)		$(4.2 \ {}^{+1.5}_{-1.8}) \times 10^{-3}$		–
$\overline{D}_2^*(2460)^0 \ell^+ \nu_\ell$ anything $\times$ B($\overline{D}_2^*(2460)^0 \to D^- \pi^+$)		$(1.6 \pm 0.8) \times 10^{-3}$		–
charmless $\ell \overline{\nu}_\ell$	[sss]	$(1.7 \pm 0.5) \times 10^{-3}$		–
$\tau^+ \nu_\tau$ anything		(2.41 ± 0.23) %		–
$D^{*-} \tau \nu_\tau$ anything		$(9 \pm 4) \times 10^{-3}$		–
$\overline{c} \to \ell^- \overline{\nu}_\ell$ anything	[sss]	(8.02 ± 0.19) %		–
$c \to \ell^+ \nu$ anything		$(1.6 \ {}^{+0.4}_{-0.5})$ %		–

Charmed meson and baryon modes

$\overline{D}^0$ anything		(59.5 ± 2.9) %		–
$D^0 D_s^\pm$ anything	[hh]	$(9.1 \ {}^{+4.0}_{-2.8})$ %		–
$D^\mp D_s^\pm$ anything	[hh]	$(4.0 \ {}^{+2.3}_{-1.8})$ %		–
$\overline{D}^0 D^0$ anything	[hh]	$(5.1 \ {}^{+2.0}_{-1.8})$ %		–
$D^0 D^\pm$ anything	[hh]	$(2.7 \ {}^{+1.8}_{-1.6})$ %		–
$D^\pm D^\mp$ anything	[hh]	$< 9 \times 10^{-3}$	CL=90%	–
D^- anything		(23.7 ± 1.8) %		–
$D^*(2010)^+$ anything		(17.3 ± 2.0) %		–
$D_1(2420)^0$ anything		(5.0 ± 1.5) %		–
$D^*(2010)^\mp D_s^\pm$ anything	[hh]	$(3.3 \ {}^{+1.6}_{-1.3})$ %		–
$D^0 D^*(2010)^\pm$ anything	[hh]	$(3.0 \ {}^{+1.1}_{-0.9})$ %		–
$D^*(2010)^\pm D^\mp$ anything	[hh]	$(2.5 \ {}^{+1.2}_{-1.0})$ %		–
$D^*(2010)^\pm D^*(2010)^\mp$ anything	[hh]	(1.2 ± 0.4) %		–
$\overline{D} D$ anything		$(10 \ {}^{+11}_{-10})$ %		–
$D_2^*(2460)^0$ anything		(4.7 ± 2.7) %		–
D_s^- anything		(14.7 ± 2.1) %		–
D_s^+ anything		(10.1 ± 3.1) %		–
Λ_c^+ anything		(7.8 ± 1.2) %		–
$\overline{c}/c$ anything	[ooaa]	(116.2 ± 3.2) %		–

Charmonium modes

$J/\psi(1S)$ anything		(1.16 ± 0.10) %		–
$\psi(2S)$ anything		$(2.86 \pm 0.28) \times 10^{-3}$		–
$\chi_{c0}(1P)$ anything		(1.5 ± 0.6) %		–
$\chi_{c1}(1P)$ anything		(1.4 ± 0.4) %		–
$\chi_{c2}(1P)$ anything		$(6.2 \pm 2.9) \times 10^{-3}$		–
$\chi_c(2P)$ anything, $\chi_c \to \phi\phi$		$< 2.8 \times 10^{-7}$	CL=95%	–
$\eta_c(1S)$ anything		(4.5 ± 1.9) %		–
$\eta_c(2S)$ anything, $\eta_c \to \phi\phi$		$(3.2 \pm 1.7) \times 10^{-6}$		–
$\chi_{c1}(3872)$ anything, $\chi_{c1} \to \phi\phi$		$< 4.5 \times 10^{-7}$	CL=95%	–
$X(3915)$ anything, $X \to \phi\phi$		$< 3.1 \times 10^{-7}$	CL=95%	–

***K* or *K** modes**

$\overline{s}\gamma$		$(3.1 \pm 1.1) \times 10^{-4}$		–
$\overline{s}\overline{\nu}\nu$	B1	$< 6.4 \times 10^{-4}$	CL=90%	–
$K^\pm$ anything		(74 ± 6) %		–
K_S^0 anything		(29.0 ± 2.9) %		–

Pion modes			
$\pi^{\pm}$ anything		(397 ± 21) %	–
π^0 anything	[*ooaa*]	(278 ± 60) %	–
ϕ anything		(2.82 ± 0.23) %	–
Baryon modes			
$p/\overline{p}$ anything		(13.1 ± 1.1) %	–
$\Lambda/\overline{\Lambda}$ anything		(5.9 ± 0.6) %	–
b-baryon anything		(10.2 ± 2.8) %	–
Other modes			
charged anything	[*ooaa*]	(497 ± 7) %	–
hadron$^+$ hadron$^-$		$(1.7 {}^{+1.0}_{-0.7}) \times 10^{-5}$	–
charmless		$(7 \pm 21) \times 10^{-3}$	–
$\Delta B = 1$ weak neutral current (*B1*) modes			
$\mu^+\mu^-$ anything	*B1*	$< 3.2 \times 10^{-4}$ CL=90%	–

B^*

$I(J^P) = \frac{1}{2}(1^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B^*} = 5324.65 \pm 0.25$ MeV
$m_{B^*} - m_B = 45.18 \pm 0.23$ MeV
$m_{B^{*+}} - m_{B^+} = 45.34 \pm 0.23$ MeV

B^* DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$B\gamma$	dominant	45

$B_1(5721)^+$

$I(J^P) = \frac{1}{2}(1^+)$
I, J, P need confirmation.

Mass $m = 5725.9^{+2.5}_{-2.7}$ MeV
$m_{B_1^+} - m_{B^{*0}} = 401.2^{+2.4}_{-2.7}$ MeV
Full width $\Gamma = 31 \pm 6$ MeV (S = 1.1)

$B_1(5721)^0$

$I(J^P) = \frac{1}{2}(1^+)$
I, J, P need confirmation.

$B_1(5721)^0$ MASS $= 5726.0 \pm 1.3$ MeV (S = 1.2)
$m_{B_1^0} - m_{B^+} = 446.7 \pm 1.3$ MeV (S = 1.2)
$m_{B_1^0} - m_{B^{*+}} = 401.4 \pm 1.2$ MeV (S = 1.2)
Full width $\Gamma = 27.5 \pm 3.4$ MeV (S = 1.1)

$B_1(5721)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$B^{*+}\pi^-$	dominant	363

$B_2^*(5747)^+$

$I(J^P) = \frac{1}{2}(2^+)$
I, J, P need confirmation.

Mass $m = 5737.2 \pm 0.7$ MeV
$m_{B_2^{*+}} - m_{B^0} = 457.5 \pm 0.7$ MeV
Full width $\Gamma = 20 \pm 5$ MeV (S = 2.2)

$B_2^*(5747)^0$

$I(J^P) = \frac{1}{2}(2^+)$
I, J, P need confirmation.

$B_2^*(5747)^0$ MASS $= 5739.5 \pm 0.7$ MeV (S = 1.4)
$m_{B_2^{*0}} - m_{B_1^0} = 13.5 \pm 1.4$ MeV (S = 1.3)
$m_{B_2^{*0}} - m_{B^+} = 460.2 \pm 0.6$ MeV (S = 1.4)
Full width $\Gamma = 24.2 \pm 1.7$ MeV

$B_2^*(5747)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$B^+\pi^-$	dominant	421
$B^{*+}\pi^-$	dominant	377

$B_J(5970)^+$

$I(J^P) = \frac{1}{2}(?^?)$
I, J, P need confirmation.

Mass $m = 5964 \pm 5$ MeV
$m_{B_J(5970)^+} - m_{B^0} = 685 \pm 5$ MeV
Full width $\Gamma = 62 \pm 20$ MeV

$B_J(5970)^0$

$I(J^P) = \frac{1}{2}(?^?)$
I, J, P need confirmation.

Mass $m = 5971 \pm 5$ MeV
$m_{B_J(5970)^0} - m_{B^+} = 691 \pm 5$ MeV
Full width $\Gamma = 81 \pm 12$ MeV

BOTTOM, STRANGE MESONS $(B = \pm 1, S = \mp 1)$

$B_s^0 = s\overline{b}$, $\overline{B}_s^0 = \overline{s}b$, similarly for B_s^*'s

B_s^0

$I(J^P) = 0(0^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B_s^0} = 5366.89 \pm 0.19$ MeV
$m_{B_s^0} - m_B = 87.42 \pm 0.19$ MeV
Mean life $\tau = (1.509 \pm 0.004) \times 10^{-12}$ s
$c\tau = 452.4\ \mu$m
$\Delta\Gamma_{B_s^0} = \Gamma_{B_{sL}^0} - \Gamma_{B_{sH}^0} = (0.088 \pm 0.006) \times 10^{12}\ \text{s}^{-1}$

B^0_s-$\overline{B}^0_s$ mixing parameters

$\Delta m_{B^0_s} = m_{B^0_{sH}} - m_{B^0_{sL}} = (17.757 \pm 0.021) \times 10^{12}\ \hbar\ s^{-1}$
$= (1.1688 \pm 0.0014) \times 10^{-8}$ MeV
$x_s = \Delta m_{B^0_s}/\Gamma_{B^0_s} = 26.79 \pm 0.08$
$\chi_s = 0.499307 \pm 0.000004$

CP violation parameters in B^0_s

$\mathrm{Re}(\epsilon_{B^0_s})\ /\ (1 + |\epsilon_{B^0_s}|^2) = (-0.15 \pm 0.70) \times 10^{-3}$
$C_{KK}(B^0_s \to K^+ K^-) = 0.14 \pm 0.11$
$S_{KK}(B^0_s \to K^+ K^-) = 0.30 \pm 0.13$
$r_B(B^0_s \to D_s^{\mp} K^{\pm}) = 0.53 \pm 0.17$
$\delta_B(B^0_s \to D_s^{\pm} K^{\mp}) = (3 \pm 20)^\circ$
CP Violation phase $\beta_s = (1.1 \pm 1.6) \times 10^{-2}$ rad
$|\lambda|\ (B^0_s \to J/\psi(1S)\phi) = 0.964 \pm 0.020$
$|\lambda| = 1.001 \pm 0.017$
A, CP violation parameter $= 0.5^{+0.8}_{-0.7}$
C, CP violation parameter $= -0.3 \pm 0.4$
S, CP violation parameter $= -0.1 \pm 0.4$
$A^L_{CP}(B_s \to J/\psi \overline{K}^*(892)^0) = -0.05 \pm 0.06$
$A^{\parallel}_{CP}(B_s \to J/\psi \overline{K}^*(892)^0) = 0.17 \pm 0.15$
$A^{\perp}_{CP}(B_s \to J/\psi \overline{K}^*(892)^0) = -0.05 \pm 0.10$
$\boldsymbol{A_{CP}(B_s \to \pi^+ K^-)} = 0.26 \pm 0.04$
$A_{CP}(B^0_s \to [K^+ K^-]_D \overline{K}^*(892)^0) = -0.04 \pm 0.07$
$A_{CP}(B^0_s \to [\pi^+ K^-]_D K^*(892)^0) = -0.01 \pm 0.04$
$A_{CP}(B^0_s \to [\pi^+ \pi^-]_D K^*(892)^0) = 0.06 \pm 0.13$
$A^{\Delta}(B_s \to \phi\gamma) = -1.0 \pm 0.5$
$\Delta a_{\perp} < 1.2 \times 10^{-12}$ GeV, CL = 95%
$\Delta a_{\parallel} = (-0.9 \pm 1.5) \times 10^{-14}$ GeV
$\Delta a_X = (1.0 \pm 2.2) \times 10^{-14}$ GeV
$\Delta a_Y = (-3.8 \pm 2.2) \times 10^{-14}$ GeV
$\mathrm{Re}(\xi) = -0.022 \pm 0.033$
$\mathrm{Im}(\xi) = 0.004 \pm 0.011$

These branching fractions all scale with $B(\overline{b} \to B^0_s)$.

The branching fraction $B(B^0_s \to D_s^- \ell^+ \nu_\ell \text{anything})$ is not a pure measurement since the measured product branching fraction $B(\overline{b} \to B^0_s) \times B(B^0_s \to D_s^- \ell^+ \nu_\ell \text{anything})$ was used to determine $B(\overline{b} \to B^0_s)$, as described in the note on "B^0-$\overline{B}^0$ Mixing"

For inclusive branching fractions, *e.g.*, $B \to D^{\pm}$anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

B^0_s DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
D_s^- anything		(93 ± 25) %		–
$\ell \nu_\ell X$		(9.6 ± 0.8) %		–
$e^+ \nu X^-$		(9.1 ± 0.8) %		–
$\mu^+ \nu X^-$		(10.2 ± 1.0) %		–
$D_s^- \ell^+ \nu_\ell$ anything	[$qqaa$]	(8.1 ± 1.3) %		–
$D_s^{*-} \ell^+ \nu_\ell$ anything		(5.4 ± 1.1) %		–

$D_{s1}(2536)^- \mu^+ \nu_\mu$, $D_{s1}^- \to D^{*-} K_S^0$	$(2.6 \pm 0.7) \times 10^{-3}$		–
$D_{s1}(2536)^- X \mu^+ \nu$, $D_{s1}^- \to \overline{D}^0 K^+$	$(4.4 \pm 1.3) \times 10^{-3}$		–
$D_{s2}(2573)^- X \mu^+ \nu$, $D_{s2}^- \to \overline{D}^0 K^+$	$(2.7 \pm 1.0) \times 10^{-3}$		–
$D_s^- \pi^+$	$(3.00 \pm 0.23) \times 10^{-3}$		2320
$D_s^- \rho^+$	$(6.9 \pm 1.4) \times 10^{-3}$		2249
$D_s^- \pi^+ \pi^+ \pi^-$	$(6.1 \pm 1.0) \times 10^{-3}$		2301
$D_{s1}(2536)^- \pi^+$, $D_{s1}^- \to D_s^- \pi^+ \pi^-$	$(2.5 \pm 0.8) \times 10^{-5}$		–
$D_s^\mp K^\pm$	$(2.27 \pm 0.19) \times 10^{-4}$		2293
$D_s^- K^+ \pi^+ \pi^-$	$(3.2 \pm 0.6) \times 10^{-4}$		2249
$D_s^+ D_s^-$	$(4.4 \pm 0.5) \times 10^{-3}$		1824
$D_s^- D^+$	$(2.8 \pm 0.5) \times 10^{-4}$		1875
$D^+ D^-$	$(2.2 \pm 0.6) \times 10^{-4}$		1925
$D^0 \overline{D}^0$	$(1.9 \pm 0.5) \times 10^{-4}$		1930
$D_s^{*-} \pi^+$	$(2.0 \pm 0.5) \times 10^{-3}$		2265
$D_s^{*\mp} K^\pm$	$(1.33 \pm 0.35) \times 10^{-4}$		–
$D_s^{*-} \rho^+$	$(9.6 \pm 2.1) \times 10^{-3}$		2191
$D_s^{*+} D_s^- + D_s^{*-} D_s^+$	(1.38 ± 0.16) %		1742
$D_s^{*+} D_s^{*-}$	(1.44 ± 0.20) %	S=1.1	1655
$D_s^{(*)+} D_s^{(*)-}$	(4.5 ± 1.4) %		–
$\overline{D}^{*0} \overline{K}^0$	$(2.8 \pm 1.1) \times 10^{-4}$		2278
$\overline{D}^0 \overline{K}^0$	$(4.3 \pm 0.9) \times 10^{-4}$		2330
$\overline{D}^0 K^- \pi^+$	$(1.04 \pm 0.13) \times 10^{-3}$		2312
$\overline{D}^0 \overline{K}^*(892)^0$	$(4.4 \pm 0.6) \times 10^{-4}$		2264
$\overline{D}^0 \overline{K}^*(1410)$	$(3.9 \pm 3.5) \times 10^{-4}$		2114
$\overline{D}^0 \overline{K}_0^*(1430)$	$(3.0 \pm 0.7) \times 10^{-4}$		2113
$\overline{D}^0 \overline{K}_2^*(1430)$	$(1.1 \pm 0.4) \times 10^{-4}$		2113
$\overline{D}^0 \overline{K}^*(1680)$	$< 7.8 \times 10^{-5}$	CL=90%	1997
$\overline{D}^0 \overline{K}_0^*(1950)$	$< 1.1 \times 10^{-4}$	CL=90%	1890
$\overline{D}^0 \overline{K}_3^*(1780)$	$< 2.6 \times 10^{-5}$	CL=90%	1971
$\overline{D}^0 \overline{K}_4^*(2045)$	$< 3.1 \times 10^{-5}$	CL=90%	1837
$\overline{D}^0 K^- \pi^+$ (non-resonant)	$(2.1 \pm 0.8) \times 10^{-4}$		2312
$D_{s2}^*(2573)^- \pi^+$, $D_{s2}^* \to \overline{D}^0 K^-$	$(2.6 \pm 0.4) \times 10^{-4}$		–
$D_{s1}^*(2700)^- \pi^+$, $D_{s1}^* \to \overline{D}^0 K^-$	$(1.6 \pm 0.8) \times 10^{-5}$		–
$D_{s1}^*(2860)^- \pi^+$, $D_{s1}^* \to \overline{D}^0 K^-$	$(5 \pm 4) \times 10^{-5}$		–
$D_{s3}^*(2860)^- \pi^+$, $D_{s3}^* \to \overline{D}^0 K^-$	$(2.2 \pm 0.6) \times 10^{-5}$		–
$\overline{D}^0 K^+ K^-$	$(4.4 \pm 2.0) \times 10^{-5}$		2243
$\overline{D}^0 f_0(980)$	$< 3.1 \times 10^{-6}$	CL=90%	2242
$\overline{D}^0 \phi$	$(3.0 \pm 0.8) \times 10^{-5}$		2235
$D^{*\mp} \pi^\pm$	$< 6.1 \times 10^{-6}$	CL=90%	–
$\eta_c \phi$	$(5.0 \pm 0.9) \times 10^{-4}$		1663
$\eta_c \pi^+ \pi^-$	$(1.8 \pm 0.7) \times 10^{-4}$		1840
$J/\psi(1S) \phi$	$(1.08 \pm 0.08) \times 10^{-3}$		1588
$J/\psi(1S) \phi \phi$	$(1.24^{+0.17}_{-0.19}) \times 10^{-5}$		764
$J/\psi(1S) \pi^0$	$< 1.2 \times 10^{-3}$	CL=90%	1787

$J/\psi(1S)\eta$	$(4.0 \pm 0.7) \times 10^{-4}$	S=1.4	1733
$J/\psi(1S)K^0_S$	$(1.88\pm 0.15) \times 10^{-5}$		1743
$J/\psi(1S)\overline{K}^*(892)^0$	$(4.1 \pm 0.4) \times 10^{-5}$		1637
$J/\psi(1S)\eta'$	$(3.3 \pm 0.4) \times 10^{-4}$		1612
$J/\psi(1S)\pi^+\pi^-$	$(2.09\pm 0.23) \times 10^{-4}$	S=1.3	1775
$J/\psi(1S)f_0(500)$, $f_0 \to \pi^+\pi^-$	$< 4 \times 10^{-6}$	CL=90%	–
$J/\psi(1S)\rho$, $\rho \to \pi^+\pi^-$	$< 4 \times 10^{-6}$	CL=90%	–
$J/\psi(1S)f_0(980)$, $f_0 \to \pi^+\pi^-$	$(1.28\pm 0.18) \times 10^{-4}$	S=1.7	–
$J/\psi(1S)f_2(1270)$, $f_2 \to \pi^+\pi^-$	$(1.1 \pm 0.4) \times 10^{-6}$		–
$J/\psi(1S)f_2(1270)_0$, $f_2 \to \pi^+\pi^-$	$(7.5 \pm 1.8) \times 10^{-7}$		–
$J/\psi(1S)f_2(1270)_\parallel$, $f_2 \to \pi^+\pi^-$	$(1.09\pm 0.34) \times 10^{-6}$		–
$J/\psi(1S)f_2(1270)_\perp$, $f_2 \to \pi^+\pi^-$	$(1.3 \pm 0.8) \times 10^{-6}$		–
$J/\psi(1S)f_0(1370)$, $f_0 \to \pi^+\pi^-$	$(4.5 {}^{+0.7}_{-4.0}) \times 10^{-5}$		–
$J/\psi(1S)f_0(1500)$, $f_0 \to \pi^+\pi^-$	$(2.11 {}^{+0.40}_{-0.29}) \times 10^{-5}$		–
$J/\psi(1S)f'_2(1525)_0$, $f'_2 \to \pi^+\pi^-$	$(1.07\pm 0.24) \times 10^{-6}$		–
$J/\psi(1S)f'_2(1525)_\parallel$, $f'_2 \to \pi^+\pi^-$	$(1.3 {}^{+2.7}_{-0.9}) \times 10^{-7}$		–
$J/\psi(1S)f'_2(1525)_\perp$, $f'_2 \to \pi^+\pi^-$	$(5 \pm 4) \times 10^{-7}$		–
$J/\psi(1S)f_0(1790)$, $f_0 \to \pi^+\pi^-$	$(5.0 {}^{+11.0}_{-1.1}) \times 10^{-6}$		–
$J/\psi(1S)\pi^+\pi^-$ (nonresonant)	$(1.8 {}^{+1.1}_{-0.4}) \times 10^{-5}$		1775
$J/\psi(1S)\overline{K}^0\pi^+\pi^-$	$< 4.4 \times 10^{-5}$	CL=90%	1675
$J/\psi(1S)K^+K^-$	$(7.9 \pm 0.7) \times 10^{-4}$		1601
$J/\psi(1S)K^0K^-\pi^+$ + c.c.	$(9.3 \pm 1.3) \times 10^{-4}$		1538
$J/\psi(1S)\overline{K}^0K^+K^-$	$< 1.2 \times 10^{-5}$	CL=90%	1333
$J/\psi(1S)f'_2(1525)$	$(2.6 \pm 0.6) \times 10^{-4}$		1304
$J/\psi(1S)p\overline{p}$	$< 4.8 \times 10^{-6}$	CL=90%	982
$J/\psi(1S)\gamma$	$< 7.3 \times 10^{-6}$	CL=90%	1790
$J/\psi(1S)\pi^+\pi^-\pi^+\pi^-$	$(7.8 \pm 1.0) \times 10^{-5}$		1731
$J/\psi(1S)f_1(1285)$	$(7.0 \pm 1.4) \times 10^{-5}$		1460
$\psi(2S)\eta$	$(3.3 \pm 0.9) \times 10^{-4}$		1338
$\psi(2S)\eta'$	$(1.29\pm 0.35) \times 10^{-4}$		1158
$\psi(2S)\pi^+\pi^-$	$(7.1 \pm 1.3) \times 10^{-5}$		1397
$\psi(2S)\phi$	$(5.4 \pm 0.6) \times 10^{-4}$		1120
$\psi(2S)K^-\pi^+$	$(3.12\pm 0.30) \times 10^{-5}$		1310
$\psi(2S)\overline{K}^*(892)^0$	$(3.3 \pm 0.5) \times 10^{-5}$		1196
$\chi_{c1}\phi$	$(2.04\pm 0.30) \times 10^{-4}$		1274
$\pi^+\pi^-$	$(7.0 \pm 0.8) \times 10^{-7}$		2680
$\pi^0\pi^0$	$< 2.1 \times 10^{-4}$	CL=90%	2680
$\eta\pi^0$	$< 1.0 \times 10^{-3}$	CL=90%	2654
$\eta\eta$	$< 1.5 \times 10^{-3}$	CL=90%	2627
$\rho^0\rho^0$	$< 3.20 \times 10^{-4}$	CL=90%	2569
$\eta'\eta'$	$(3.3 \pm 0.7) \times 10^{-5}$		2507
$\eta'\phi$	$< 8.2 \times 10^{-7}$	CL=90%	2495
$\phi f_0(980)$, $f_0(980) \to \pi^+\pi^-$	$(1.12\pm 0.21) \times 10^{-6}$		–

$\phi f_2(1270)$, $f_2(1270) \to \pi^+\pi^-$			$(6.1\ ^{+}_{-}\ ^{1.8}_{1.5}) \times 10^{-7}$		–
$\phi\rho^0$			$(2.7 \pm 0.8) \times 10^{-7}$		2526
$\phi\pi^+\pi^-$			$(3.5 \pm 0.5) \times 10^{-6}$		2579
$\phi\phi$			$(1.87 \pm 0.15) \times 10^{-5}$		2482
$\phi\phi\phi$			$(2.2 \pm 0.7) \times 10^{-6}$		2165
π^+K^-			$(5.7 \pm 0.6) \times 10^{-6}$		2659
K^+K^-			$(2.59 \pm 0.17) \times 10^{-5}$		2638
$K^0\overline{K}^0$			$(2.0 \pm 0.6) \times 10^{-5}$		2637
$K^0\pi^+\pi^-$			$(9.4 \pm 2.1) \times 10^{-6}$		2653
$K^0K^\pm\pi^\mp$			$(8.4 \pm 0.9) \times 10^{-5}$		2622
$K^*(892)^-\pi^+$			$(3.3 \pm 1.2) \times 10^{-6}$		2607
$K^*(892)^\pm K^\mp$			$(1.25 \pm 0.26) \times 10^{-5}$		2585
$K^0_S\overline{K}^*(892)^0$ + c.c.			$(1.6 \pm 0.4) \times 10^{-5}$		2585
$K^0K^+K^-$			$(1.3 \pm 0.6) \times 10^{-6}$		2568
$\overline{K}^*(892)^0\rho^0$			$< 7.67 \times 10^{-4}$	CL=90%	2550
$\overline{K}^*(892)^0K^*(892)^0$			$(1.11 \pm 0.27) \times 10^{-5}$		2531
$\phi K^*(892)^0$			$(1.14 \pm 0.30) \times 10^{-6}$		2507
$p\overline{p}$			$< 1.5 \times 10^{-8}$	CL=90%	2514
$p\overline{p}K^+K^-$			$(4.5 \pm 0.5) \times 10^{-6}$		2231
$p\overline{p}K^+\pi^-$			$(1.39 \pm 0.26) \times 10^{-6}$		2355
$p\overline{p}\pi^+\pi^-$			$(4.3 \pm 2.0) \times 10^{-7}$		2454
$p\overline{\Lambda}K^-$ + c.c.			$(5.5 \pm 1.0) \times 10^{-6}$		2358
$\Lambda_c^-\Lambda\pi^+$			$(3.6 \pm 1.6) \times 10^{-4}$		–
$\Lambda_c^-\Lambda_c^+$			$< 8.0 \times 10^{-5}$	CL=95%	–

Lepton Family number (*LF*) violating modes or
$\Delta B = 1$ weak neutral current (*B1*) modes

$\gamma\gamma$	*B1*		$< 3.1 \times 10^{-6}$	CL=90%	2683
$\phi\gamma$	*B1*		$(3.4 \pm 0.4) \times 10^{-5}$		2587
$\mu^+\mu^-$	*B1*		$(2.7\ ^{+}_{-}\ ^{0.6}_{0.5}) \times 10^{-9}$	S=1.2	2681
e^+e^-	*B1*		$< 2.8 \times 10^{-7}$	CL=90%	2683
$\tau^+\tau^-$	*B1*		$< 6.8 \times 10^{-3}$	CL=95%	2011
$\mu^+\mu^-\mu^+\mu^-$	*B1*		$< 2.5 \times 10^{-9}$	CL=95%	2673
SP, $S \to \mu^+\mu^-$, $P \to \mu^+\mu^-$	*B1*	[*ggaa*]	$< 2.2 \times 10^{-9}$	CL=95%	–
$\phi(1020)\mu^+\mu^-$	*B1*		$(8.2 \pm 1.2) \times 10^{-7}$		2582
$\pi^+\pi^-\mu^+\mu^-$	*B1*		$(8.4 \pm 1.7) \times 10^{-8}$		2670
$\phi\nu\overline{\nu}$	*B1*		$< 5.4 \times 10^{-3}$	CL=90%	2587
$e^\pm\mu^\mp$	*LF*	[*hh*]	$< 1.1 \times 10^{-8}$	CL=90%	2682

B_s^*

$I(J^P) = 0(1^-)$

I, *J*, *P* need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m = 5415.4^{+1.8}_{-1.5}$ MeV (S = 2.9)

$m_{B_s^*} - m_{B_s} = 48.5^{+1.8}_{-1.5}$ MeV (S = 2.8)

B_s^* DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$B_s\gamma$	dominant	48

$B_{s1}(5830)^0$

$I(J^P) = 0(1^+)$
I, J, P need confirmation.

Mass $m = 5828.63 \pm 0.27$ MeV
$m_{B_{s1}^0} - m_{B^{*+}} = 503.98 \pm 0.18$ MeV
Full width $\Gamma = 0.5 \pm 0.4$ MeV

$B_{s1}(5830)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$B^{*+} K^-$	dominant	97

$B_{s2}^*(5840)^0$

$I(J^P) = 0(2^+)$
I, J, P need confirmation.

Mass $m = 5839.85 \pm 0.17$ MeV (S = 1.1)
$m_{B_{s2}^{*0}} - m_{B^+} = 560.53 \pm 0.17$ MeV (S = 1.1)
Full width $\Gamma = 1.47 \pm 0.33$ MeV

$B_{s2}^*(5840)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$B^+ K^-$	dominant	252

BOTTOM, CHARMED MESONS ($B = C = \pm 1$)

$B_c^+ = c\overline{b}$, $B_c^- = \overline{c}b$, similarly for B_c^*'s

B_c^+

$I(J^P) = 0(0^-)$
I, J, P need confirmation.

Quantum numbers shown are quark-model predicitions.

Mass $m = 6274.9 \pm 0.8$ MeV
Mean life $\tau = (0.507 \pm 0.009) \times 10^{-12}$ s

B_c^- modes are charge conjugates of the modes below.

B_c^+ DECAY MODES × B($\overline{b} \to B_c$)	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
The following quantities are not pure branching ratios; rather the fraction $\Gamma_i/\Gamma \times$ B($\overline{b} \to B_c$).			
$J/\psi(1S)\ell^+\nu_\ell$ anything	$(8.1 \pm 1.2) \times 10^{-5}$		–
$J/\psi(1S)a_1(1260)$	$< 1.2 \times 10^{-3}$	90%	2169
$\chi_c^0\pi^+$	$(2.4 {}^{+0.9}_{-0.8}) \times 10^{-5}$		2205
$D^0 K^+$	$(3.8 {}^{+1.2}_{-1.0}) \times 10^{-7}$		2837
$D^0\pi^+$	$< 1.6 \times 10^{-7}$	95%	2858
$D^{*0}\pi^+$	$< 4 \times 10^{-7}$	95%	2815
$D^{*0}K^+$	$< 4 \times 10^{-7}$	95%	2793
$D^*(2010)^+\overline{D}^0$	$< 6.2 \times 10^{-3}$	90%	2467
D^+K^{*0}	$< 0.20 \times 10^{-6}$	90%	2783
$D^+\overline{K}^{*0}$	$< 0.16 \times 10^{-6}$	90%	2783
$D_s^+K^{*0}$	$< 0.28 \times 10^{-6}$	90%	2751
$D_s^+\overline{K}^{*0}$	$< 0.4 \times 10^{-6}$	90%	2751

$D_s^+ \phi$	< 0.32	$\times 10^{-6}$	90%	2727
$K^+ K^0$	< 4.6	$\times 10^{-7}$	90%	3098
$B_s^0 \pi^+$ / B($\overline{b} \rightarrow B_s$)	$(2.37^{+0.37}_{-0.35}) \times 10^{-3}$			–

See Particle Listings for 14 decay modes that have been seen / not seen.

$c\overline{c}$ MESONS (including possibly non-$q\overline{q}$ states)

$\eta_c(1S)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 2983.9 \pm 0.5$ MeV (S = 1.3)
Full width $\Gamma = 32.0 \pm 0.8$ MeV

$\eta_c(1S)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
Decays involving hadronic resonances			
$\eta'(958)\pi\pi$	(4.1 ± 1.7) %		1323
$\rho\rho$	(1.8 ± 0.5) %		1275
$K^*(892)^0 K^- \pi^+$ + c.c.	(2.0 ± 0.7) %		1278
$K^*(892)\overline{K}^*(892)$	$(7.1 \pm 1.3) \times 10^{-3}$		1196
$K^*(892)^0 \overline{K}^*(892)^0 \pi^+\pi^-$	(1.1 ± 0.5) %		1073
$\phi K^+ K^-$	$(2.9 \pm 1.4) \times 10^{-3}$		1104
$\phi\phi$	$(1.79 \pm 0.20) \times 10^{-3}$		1089
$\phi 2(\pi^+\pi^-)$	$< 4 \times 10^{-3}$	90%	1251
$a_0(980)\pi$	< 2 %	90%	1327
$a_2(1320)\pi$	< 2 %	90%	1196
$K^*(892)\overline{K}$ + c.c.	< 1.28 %	90%	1310
$f_2(1270)\eta$	< 1.1 %	90%	1145
$\omega\omega$	$< 3.1 \times 10^{-3}$	90%	1270
$\omega\phi$	$< 2.5 \times 10^{-4}$	90%	1185
$f_2(1270) f_2(1270)$	$(9.8 \pm 2.5) \times 10^{-3}$		774
$f_2(1270) f_2'(1525)$	$(9.8 \pm 3.2) \times 10^{-3}$		513
Decays into stable hadrons			
$K\overline{K}\pi$	(7.3 ± 0.5) %		1381
$K\overline{K}\eta$	(1.36 ± 0.16) %		1265
$\eta\pi^+\pi^-$	(1.7 ± 0.5) %		1428
$\eta 2(\pi^+\pi^-)$	(4.4 ± 1.3) %		1386
$K^+K^-\pi^+\pi^-$	$(6.9 \pm 1.1) \times 10^{-3}$		1345
$K^+K^-\pi^+\pi^-\pi^0$	(3.5 ± 0.6) %		1304
$K^0 K^- \pi^+\pi^-\pi^+$ +c.c.	(5.6 ± 1.5) %		–
$K^+K^- 2(\pi^+\pi^-)$	$(7.5 \pm 2.4) \times 10^{-3}$		1254
$2(K^+K^-)$	$(1.47 \pm 0.31) \times 10^{-3}$		1055
$\pi^+\pi^-\pi^0$	$< 5 \times 10^{-4}$	90%	1476
$\pi^+\pi^-\pi^0\pi^0$	(4.7 ± 1.0) %		1460
$2(\pi^+\pi^-)$	$(9.7 \pm 1.2) \times 10^{-3}$		1459
$2(\pi^+\pi^-\pi^0)$	(17.4 ± 3.3) %		1409
$3(\pi^+\pi^-)$	(1.8 ± 0.4) %		1407
$p\overline{p}$	$(1.52 \pm 0.16) \times 10^{-3}$		1160
$p\overline{p}\pi^0$	$(3.6 \pm 1.3) \times 10^{-3}$		1101
$\Lambda\overline{\Lambda}$	$(1.09 \pm 0.24) \times 10^{-3}$		991
$\Sigma^+\overline{\Sigma}^-$	$(2.1 \pm 0.6) \times 10^{-3}$		901

$\Xi^- \overline{\Xi}^+$		$(9.0 \pm 2.6) \times 10^{-4}$		692
$\pi^+ \pi^- p \overline{p}$		$(5.3 \pm 1.8) \times 10^{-3}$		1027

Radiative decays

$\gamma\gamma$		$(1.57 \pm 0.12) \times 10^{-4}$		1492

Charge conjugation (C), Parity (P), Lepton family number (LF) violating modes

$\pi^+ \pi^-$	P,CP	$< 1.1 \times 10^{-4}$	90%	1485
$\pi^0 \pi^0$	P,CP	$< 4 \times 10^{-5}$	90%	1486
$K^+ K^-$	P,CP	$< 6 \times 10^{-4}$	90%	1408
$K^0_S K^0_S$	P,CP	$< 3.1 \times 10^{-4}$	90%	1406

See Particle Listings for 11 decay modes that have been seen / not seen.

$J/\psi(1S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 3096.900 \pm 0.006$ MeV
Full width $\Gamma = 92.9 \pm 2.8$ keV (S = 1.1)
$\Gamma_{ee} = 5.55 \pm 0.14 \pm 0.02$ keV

$J/\psi(1S)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
hadrons		(87.7 ± 0.5) %		–
virtual$\gamma \to$ hadrons		(13.50 ± 0.30) %		–
ggg		(64.1 ± 1.0) %		–
γgg		(8.8 ± 1.1) %		–
$e^+ e^-$		(5.971 ± 0.032) %		1548
$e^+ e^- \gamma$	[rraa]	$(8.8 \pm 1.4) \times 10^{-3}$		1548
$\mu^+ \mu^-$		(5.961 ± 0.033) %		1545

Decays involving hadronic resonances

$\rho\pi$		(1.69 ± 0.15) %	S=2.4	1448
$\rho^0 \pi^0$		$(5.6 \pm 0.7) \times 10^{-3}$		1448
$\rho(770)^{\mp} K^{\pm} K^0_S$		$(1.9 \pm 0.4) \times 10^{-3}$		–
$\rho(1450)\pi \to \pi^+ \pi^- \pi^0$		$(2.3 \pm 0.7) \times 10^{-3}$		–
$\rho(1450)^{\pm} \pi^{\mp} \to K^0_S K^{\pm} \pi^{\mp}$		$(3.5 \pm 0.6) \times 10^{-4}$		–
$\rho(1450)^0 \pi^0 \to K^+ K^- \pi^0$		$(2.0 \pm 0.5) \times 10^{-4}$		–
$\rho(1450)\eta'(958) \to \pi^+ \pi^- \eta'(958)$		$(3.3 \pm 0.7) \times 10^{-6}$		–
$\rho(1700)\pi \to \pi^+ \pi^- \pi^0$		$(1.7 \pm 1.1) \times 10^{-4}$		–
$\rho(2150)\pi \to \pi^+ \pi^- \pi^0$		$(8 \pm 40) \times 10^{-6}$		–
$a_2(1320)\rho$		(1.09 ± 0.22) %		1123
$\omega \pi^+ \pi^+ \pi^- \pi^-$		$(8.5 \pm 3.4) \times 10^{-3}$		1392
$\omega \pi^+ \pi^- \pi^0$		$(4.0 \pm 0.7) \times 10^{-3}$		1418
$\omega \pi^+ \pi^-$		$(8.6 \pm 0.7) \times 10^{-3}$	S=1.1	1435
$\omega f_2(1270)$		$(4.3 \pm 0.6) \times 10^{-3}$		1142
$K^*(892)^0 \overline{K}^*(892)^0$		$(2.3 \pm 0.6) \times 10^{-4}$		1266
$K^*(892)^{\pm} K^*(892)^{\mp}$		$(1.00 {}^{+0.22}_{-0.40}) \times 10^{-3}$		1266
$K^*(892)^{\pm} K^*(700)^{\mp}$		$(1.1 {}^{+1.0}_{-0.6}) \times 10^{-3}$		–
$K^0_S \pi^- K^*(892)^+ +$ c.c.		$(2.0 \pm 0.5) \times 10^{-3}$		1342
$K^0_S \pi^- K^*(892)^+ +$ c.c. $\to K^0_S K^0_S \pi^+ \pi^-$		$(6.7 \pm 2.2) \times 10^{-4}$		–
$\eta K^*(892)^0 \overline{K}^*(892)^0$		$(1.15 \pm 0.26) \times 10^{-3}$		1003
$K^*(1410)\overline{K}$ +c.c $\to K^{\pm} K^{\mp} \pi^0$		$(4.9 \pm 2.8) \times 10^{-5}$		–

$K^*(1410)\overline{K}$ + c.c. $\rightarrow$ $K^0_S K^\pm \pi^\mp$		$(8 \pm 6) \times 10^{-5}$		–
$K^*_2(1430)\overline{K}$ +c.c. $\rightarrow$ $K^\pm K^\mp \pi^0$		$(7.5 \pm 3.5) \times 10^{-5}$		–
$K^*_2(1430)\overline{K}$ + c.c. $\rightarrow$ $K^0_S K^\pm \pi^\mp$		$(4.0 \pm 1.0) \times 10^{-4}$		–
$K^*(892)^0 \overline{K}^*_2(1430)^0$ + c.c.		$(4.66 \pm 0.31) \times 10^{-3}$		1012
$K^*(892)^+ K^*_2(1430)^-$ + c.c.		$(3.4 \pm 2.9) \times 10^{-3}$		1012
$K^*(892)^+ K^*_2(1430)^-$ + c.c. $\rightarrow$ $K^*(892)^+ K^0_S \pi^-$ + c.c.		$(4 \pm 4) \times 10^{-4}$		–
$K^*(892)^0 \overline{K}_2(1770)^0$ + c.c. $\rightarrow$ $K^*(892)^0 K^- \pi^+$ + c.c.		$(6.9 \pm 0.9) \times 10^{-4}$		–
$\omega K^*(892)\overline{K}$ + c.c.		$(6.1 \pm 0.9) \times 10^{-3}$		1097
$\overline{K} K^*(892)$ +c.c. $\rightarrow$ $K^0_S K^\pm \pi^\mp$		$(5.1 \pm 0.5) \times 10^{-3}$		–
$K^+ K^*(892)^-$ + c.c.		$(5.12 \pm 0.30) \times 10^{-3}$		1373
$K^+ K^*(892)^-$ + c.c. $\rightarrow$ $K^+ K^- \pi^0$		$(1.97 \pm 0.20) \times 10^{-3}$		–
$K^+ K^*(892)^-$ + c.c. $\rightarrow$ $K^0 K^\pm \pi^\mp$ + c.c.		$(3.0 \pm 0.4) \times 10^{-3}$		–
$K^0 \overline{K}^*(892)^0$ + c.c.		$(4.39 \pm 0.31) \times 10^{-3}$		1373
$K^0 \overline{K}^*(892)^0$ + c.c. $\rightarrow$ $K^0 K^\pm \pi^\mp$ + c.c.		$(3.2 \pm 0.4) \times 10^{-3}$		–
$K_1(1400)^\pm K^\mp$		$(3.8 \pm 1.4) \times 10^{-3}$		1170
$K^*(892)^\pm K^\mp \pi^0$		$(4.1 \pm 1.3) \times 10^{-3}$		1344
$K^*(892)^0 K^0_S \pi^0$		$(6 \pm 4) \times 10^{-4}$		1343
$\omega \pi^0 \pi^0$		$(3.4 \pm 0.8) \times 10^{-3}$		1436
$b_1(1235)^\pm \pi^\mp$	[hh]	$(3.0 \pm 0.5) \times 10^{-3}$		1300
$\omega K^\pm K^0_S \pi^\mp$	[hh]	$(3.4 \pm 0.5) \times 10^{-3}$		1210
$b_1(1235)^0 \pi^0$		$(2.3 \pm 0.6) \times 10^{-3}$		1300
$\eta K^\pm K^0_S \pi^\mp$	[hh]	$(2.2 \pm 0.4) \times 10^{-3}$		1278
$\phi K^*(892)\overline{K}$ + c.c.		$(2.18 \pm 0.23) \times 10^{-3}$		969
$\omega K \overline{K}$		$(1.70 \pm 0.32) \times 10^{-3}$		1268
$\omega f_0(1710) \rightarrow \omega K \overline{K}$		$(4.8 \pm 1.1) \times 10^{-4}$		878
$\phi 2(\pi^+ \pi^-)$		$(1.66 \pm 0.23) \times 10^{-3}$		1318
$\Delta(1232)^{++} \overline{p} \pi^-$		$(1.6 \pm 0.5) \times 10^{-3}$		1030
$\omega \eta$		$(1.74 \pm 0.20) \times 10^{-3}$	S=1.6	1394
$\phi K \overline{K}$		$(1.77 \pm 0.16) \times 10^{-3}$	S=1.3	1179
$\phi K^0_S K^0_S$		$(5.9 \pm 1.5) \times 10^{-4}$		1176
$\phi f_0(1710) \rightarrow \phi K \overline{K}$		$(3.6 \pm 0.6) \times 10^{-4}$		875
$\phi K^+ K^-$		$(8.3 \pm 1.2) \times 10^{-4}$		1179
$\phi f_2(1270)$		$(3.2 \pm 0.6) \times 10^{-4}$		1036
$\Delta(1232)^{++} \overline{\Delta}(1232)^{--}$		$(1.10 \pm 0.29) \times 10^{-3}$		938
$\Sigma(1385)^- \overline{\Sigma}(1385)^+$ (or c.c.)	[hh]	$(1.16 \pm 0.05) \times 10^{-3}$		697
$\Sigma(1385)^0 \overline{\Sigma}(1385)^0$		$(1.07 \pm 0.08) \times 10^{-3}$		697
$K^+ K^- f'_2(1525)$		$(1.04 \pm 0.35) \times 10^{-3}$		892
$\phi f'_2(1525)$		$(8 \pm 4) \times 10^{-4}$	S=2.7	871
$\phi \pi^+ \pi^-$		$(8.7 \pm 0.9) \times 10^{-4}$	S=1.4	1365
$\phi \pi^0 \pi^0$		$(5.0 \pm 1.0) \times 10^{-4}$		1366
$\phi K^\pm K^0_S \pi^\mp$	[hh]	$(7.2 \pm 0.8) \times 10^{-4}$		1114
$\omega f_1(1420)$		$(6.8 \pm 2.4) \times 10^{-4}$		1062
$\phi \eta$		$(7.5 \pm 0.8) \times 10^{-4}$	S=1.5	1320
$\Xi^0 \overline{\Xi}^0$		$(1.17 \pm 0.04) \times 10^{-3}$		818
$\Xi(1530)^- \overline{\Xi}^+$		$(5.9 \pm 1.5) \times 10^{-4}$		600

$pK^-\overline{\Sigma}(1385)^0$		$(5.1 \pm 3.2) \times 10^{-4}$		646
$\omega\pi^0$		$(4.5 \pm 0.5) \times 10^{-4}$	S=1.4	1446
$\quad\omega\pi^0 \to \pi^+\pi^-\pi^0$		$(1.7 \pm 0.8) \times 10^{-5}$		–
$\phi\eta'(958)$		$(4.6 \pm 0.5) \times 10^{-4}$	S=2.2	1192
$\phi f_0(980)$		$(3.2 \pm 0.9) \times 10^{-4}$	S=1.9	1178
$\quad\phi f_0(980) \to \phi\pi^+\pi^-$		$(2.59 \pm 0.34) \times 10^{-4}$		–
$\quad\phi f_0(980) \to \phi\pi^0\pi^0$		$(1.8 \pm 0.5) \times 10^{-4}$		–
$\phi\pi^0 f_0(980) \to \phi\pi^0\pi^+\pi^-$		$(4.5 \pm 1.0) \times 10^{-6}$		–
$\phi\pi^0 f_0(980) \to \phi\pi^0 p^0\pi^0$		$(1.7 \pm 0.6) \times 10^{-6}$		1045
$\eta\phi f_0(980) \to \eta\phi\pi^+\pi^-$		$(3.2 \pm 1.0) \times 10^{-4}$		–
$\phi a_0(980)^0 \to \phi\eta\pi^0$		$(5 \pm 4) \times 10^{-6}$		–
$\Xi(1530)^0\overline{\Xi}^0$		$(3.2 \pm 1.4) \times 10^{-4}$		608
$\Sigma(1385)^-\overline{\Sigma}^+$ (or c.c.)	[hh]	$(3.1 \pm 0.5) \times 10^{-4}$		855
$\phi f_1(1285)$		$(2.6 \pm 0.5) \times 10^{-4}$		1032
$\quad\phi f_1(1285) \to \phi\pi^0 f_0(980) \to \phi\pi^0\pi^+\pi^-$		$(9.4 \pm 2.8) \times 10^{-7}$		952
$\quad\phi f_1(1285) \to \phi\pi^0 f_0(980) \to \phi\pi^0\pi^0\pi^0$		$(2.1 \pm 2.2) \times 10^{-7}$		955
$\eta\pi^+\pi^-$		$(4.0 \pm 1.7) \times 10^{-4}$		1487
$\quad\eta\rho$		$(1.93 \pm 0.23) \times 10^{-4}$		1396
$\omega\eta'(958)$		$(1.89 \pm 0.18) \times 10^{-4}$		1279
$\omega f_0(980)$		$(1.4 \pm 0.5) \times 10^{-4}$		1267
$\rho\eta'(958)$		$(8.1 \pm 0.8) \times 10^{-5}$	S=1.6	1281
$a_2(1320)^\pm\pi^\mp$	[hh]	$< 4.3 \times 10^{-3}$	CL=90%	1263
$K\overline{K}{}^*_2(1430)+$ c.c.		$< 4.0 \times 10^{-3}$	CL=90%	1159
$K_1(1270)^\pm K^\mp$		$< 3.0 \times 10^{-3}$	CL=90%	1231
$K^0_S\pi^- K^*_2(1430)^+ +$ c.c.		$(3.6 \pm 1.8) \times 10^{-3}$		1117
$K^0_S\pi^- K^*_2(1430)^+ +$ c.c. $\to K^0_S K^0_S\pi^+\pi^-$		$(4.5 \pm 2.2) \times 10^{-4}$		–
$K^*_2(1430)^0\overline{K}{}^*_2(1430)^0$		$< 2.9 \times 10^{-3}$	CL=90%	604
$\phi\pi^0$		3×10^{-6} or 1×10^{-7}		1377
$\phi\eta(1405) \to \phi\eta\pi^+\pi^-$		$(2.0 \pm 1.0) \times 10^{-5}$		946
$\omega f'_2(1525)$		$< 2.2 \times 10^{-4}$	CL=90%	1003
$\omega X(1835) \to \omega p\overline{p}$		$< 3.9 \times 10^{-6}$	CL=95%	–
$\phi X(1835) \to \phi p\overline{p}$		$< 2.1 \times 10^{-7}$	CL=90%	–
$\phi X(1835) \to \phi\eta\pi^+\pi^-$		$< 2.8 \times 10^{-4}$	CL=90%	578
$\phi X(1870) \to \phi\eta\pi^+\pi^-$		$< 6.13 \times 10^{-5}$	CL=90%	–
$\eta\phi(2170) \to \eta\phi f_0(980) \to \eta\phi\pi^+\pi^-$		$(1.2 \pm 0.4) \times 10^{-4}$		628
$\eta\phi(2170) \to \eta K^*(892)^0\overline{K}{}^*(892)^0$		$< 2.52 \times 10^{-4}$	CL=90%	–
$\Sigma(1385)^0\overline{\Lambda}+$ c.c.		$< 8.2 \times 10^{-6}$	CL=90%	912
$\Delta(1232)^+\overline{p}$		$< 1 \times 10^{-4}$	CL=90%	1100
$\Lambda(1520)\overline{\Lambda}+$ c.c. $\to \gamma\Lambda\overline{\Lambda}$		$< 4.1 \times 10^{-6}$	CL=90%	–
$\Theta(1540)\overline{\Theta}(1540) \to K^0_S pK^-\overline{n}+$ c.c.		$< 1.1 \times 10^{-5}$	CL=90%	–
$\Theta(1540)K^-\overline{n} \to K^0_S pK^-\overline{n}$		$< 2.1 \times 10^{-5}$	CL=90%	–
$\Theta(1540)K^0_S\overline{p} \to K^0_S\overline{p}K^+n$		$< 1.6 \times 10^{-5}$	CL=90%	–
$\overline{\Theta}(1540)K^+n \to K^0_S\overline{p}K^+n$		$< 5.6 \times 10^{-5}$	CL=90%	–
$\overline{\Theta}(1540)K^0_S p \to K^0_S pK^-\overline{n}$		$< 1.1 \times 10^{-5}$	CL=90%	–
$\Sigma^0\overline{\Lambda}$		$< 9 \times 10^{-5}$	CL=90%	1032

Decays into stable hadrons

$2(\pi^+\pi^-)\pi^0$		$(4.1 \pm 0.5)\ \%$	S=2.4	1496
$3(\pi^+\pi^-)\pi^0$		$(2.9 \pm 0.6)\ \%$		1433
$\pi^+\pi^-\pi^0$		$(2.11 \pm 0.07)\ \%$	S=1.5	1533
$\pi^+\pi^-\pi^0 K^+ K^-$		$(1.79 \pm 0.29)\ \%$	S=2.2	1368
$4(\pi^+\pi^-)\pi^0$		$(9.0 \pm 3.0) \times 10^{-3}$		1345
$\pi^+\pi^- K^+ K^-$		$(6.84 \pm 0.32) \times 10^{-3}$		1407
$\pi^+\pi^- K^0_S K^0_L$		$(3.8 \pm 0.6) \times 10^{-3}$		1406
$\pi^+\pi^- K^0_S K^0_S$		$(1.68 \pm 0.19) \times 10^{-3}$		1406
$\pi^\pm\pi^0 K^\mp K^0_S$		$(5.7 \pm 0.5) \times 10^{-3}$		1408
$K^+ K^- K^0_S K^0_S$		$(4.1 \pm 0.8) \times 10^{-4}$		1127
$\pi^+\pi^- K^+ K^-\eta$		$(1.84 \pm 0.28) \times 10^{-3}$		1221
$\pi^0\pi^0 K^+ K^-$		$(2.12 \pm 0.23) \times 10^{-3}$		1410
$\pi^0\pi^0 K^0_S K^0_L$		$(1.9 \pm 0.4) \times 10^{-3}$		1408
$K\overline{K}\pi$		$(6.1 \pm 1.0) \times 10^{-3}$		1442
$K^+ K^-\pi^0$		$(2.14 \pm 0.24) \times 10^{-3}$		1442
$K^0_S K^\pm\pi^\mp$		$(5.6 \pm 0.5) \times 10^{-3}$		1440
$K^0_S K^0_L\pi^0$		$(2.06 \pm 0.27) \times 10^{-3}$		1440
$K^*(892)^0\overline{K}^0$ + c.c. $\to K^0_S K^0_L\pi^0$		$(1.21 \pm 0.18) \times 10^{-3}$		–
$K^*_2(1430)^0\overline{K}^0$ + c.c. $\to K^0_S K^0_L\pi^0$		$(4.3 \pm 1.3) \times 10^{-4}$		–
$K^0_S K^0_L\eta$		$(1.44 \pm 0.34) \times 10^{-3}$		1328
$2(\pi^+\pi^-)$		$(3.57 \pm 0.30) \times 10^{-3}$		1517
$3(\pi^+\pi^-)$		$(4.3 \pm 0.4) \times 10^{-3}$		1466
$2(\pi^+\pi^-\pi^0)$		$(1.62 \pm 0.21)\ \%$		1468
$2(\pi^+\pi^-)\eta$		$(2.29 \pm 0.24) \times 10^{-3}$		1446
$3(\pi^+\pi^-)\eta$		$(7.2 \pm 1.5) \times 10^{-4}$		1379
$p\overline{p}$		$(2.121 \pm 0.029) \times 10^{-3}$		1232
$p\overline{p}\pi^0$		$(1.19 \pm 0.08) \times 10^{-3}$	S=1.1	1176
$p\overline{p}\pi^+\pi^-$		$(6.0 \pm 0.5) \times 10^{-3}$	S=1.3	1107
$p\overline{p}\pi^+\pi^-\pi^0$	[ssaa]	$(2.3 \pm 0.9) \times 10^{-3}$	S=1.9	1033
$p\overline{p}\eta$		$(2.00 \pm 0.12) \times 10^{-3}$		948
$p\overline{p}\rho$		$< 3.1 \times 10^{-4}$	CL=90%	774
$p\overline{p}\omega$		$(9.8 \pm 1.0) \times 10^{-4}$	S=1.3	768
$p\overline{p}\eta'(958)$		$(2.1 \pm 0.4) \times 10^{-4}$		596
$p\overline{p}a_0(980) \to p\overline{p}\pi^0\eta$		$(6.8 \pm 1.8) \times 10^{-5}$		–
$p\overline{p}\phi$		$(5.19 \pm 0.33) \times 10^{-5}$		527
$n\overline{n}$		$(2.09 \pm 0.16) \times 10^{-3}$		1231
$n\overline{n}\pi^+\pi^-$		$(4 \pm 4) \times 10^{-3}$		1106
$\Sigma^+\overline{\Sigma}^-$		$(1.50 \pm 0.24) \times 10^{-3}$		992
$\Sigma^0\overline{\Sigma}^0$		$(1.172 \pm 0.031) \times 10^{-3}$	S=1.4	988
$2(\pi^+\pi^-)K^+K^-$		$(4.7 \pm 0.7) \times 10^{-3}$	S=1.3	1320
$p\overline{n}\pi^-$		$(2.12 \pm 0.09) \times 10^{-3}$		1174
$\Xi^-\overline{\Xi}^+$		$(9.7 \pm 0.8) \times 10^{-4}$	S=1.4	807
$\Lambda\overline{\Lambda}$		$(1.89 \pm 0.08) \times 10^{-3}$	S=2.5	1074
$\Lambda\overline{\Sigma}^-\pi^+$ (or c.c.)	[hh]	$(8.3 \pm 0.7) \times 10^{-4}$	S=1.2	950
$pK^-\overline{\Lambda}$		$(8.9 \pm 1.6) \times 10^{-4}$		876
$2(K^+K^-)$		$(7.4 \pm 0.7) \times 10^{-4}$		1131
$pK^-\overline{\Sigma}^0$		$(2.9 \pm 0.8) \times 10^{-4}$		819
K^+K^-		$(2.86 \pm 0.21) \times 10^{-4}$		1468
$K^0_S K^0_L$		$(1.95 \pm 0.11) \times 10^{-4}$	S=2.4	1466
$\Lambda\overline{\Lambda}\pi^+\pi^-$		$(4.3 \pm 1.0) \times 10^{-3}$		903
$\Lambda\overline{\Lambda}\eta$		$(1.62 \pm 0.17) \times 10^{-4}$		672

$\Lambda \overline{\Lambda} \pi^0$		$(3.8 \pm 0.4) \times 10^{-5}$		998
$\overline{\Lambda} n K^0_S$ + c.c.		$(6.5 \pm 1.1) \times 10^{-4}$		872
$\pi^+ \pi^-$		$(1.47 \pm 0.14) \times 10^{-4}$		1542
$\Lambda \overline{\Sigma}$ + c.c.		$(2.83 \pm 0.23) \times 10^{-5}$		1034
$K^0_S K^0_S$		$< 1.4 \times 10^{-8}$	CL=95%	1466

Radiative decays

3γ		$(1.16 \pm 0.22) \times 10^{-5}$		1548
4γ		$< 9 \times 10^{-6}$	CL=90%	1548
5γ		$< 1.5 \times 10^{-5}$	CL=90%	1548
$\gamma \pi^0 \pi^0$		$(1.15 \pm 0.05) \times 10^{-3}$		1543
$\gamma \eta \pi^0$		$(2.14 \pm 0.31) \times 10^{-5}$		1497
$\gamma a_0(980)^0 \to \gamma \eta \pi^0$		$< 2.5 \times 10^{-6}$	CL=95%	–
$\gamma a_2(1320)^0 \to \gamma \eta \pi^0$		$< 6.6 \times 10^{-6}$	CL=95%	–
$\gamma \eta_c(1S)$		(1.7 ± 0.4) %	S=1.5	111
$\gamma \eta_c(1S) \to 3\gamma$		$(3.8 ^{+1.3}_{-1.0}) \times 10^{-6}$	S=1.1	–
$\gamma \pi^+ \pi^- 2\pi^0$		$(8.3 \pm 3.1) \times 10^{-3}$		1518
$\gamma \eta \pi \pi$		$(6.1 \pm 1.0) \times 10^{-3}$		1487
$\gamma \eta_2(1870) \to \gamma \eta \pi^+ \pi^-$		$(6.2 \pm 2.4) \times 10^{-4}$		–
$\gamma \eta(1405/1475) \to \gamma K \overline{K} \pi$	[o]	$(2.8 \pm 0.6) \times 10^{-3}$	S=1.6	1223
$\gamma \eta(1405/1475) \to \gamma \gamma \rho^0$		$(7.8 \pm 2.0) \times 10^{-5}$	S=1.8	1223
$\gamma \eta(1405/1475) \to \gamma \eta \pi^+ \pi^-$		$(3.0 \pm 0.5) \times 10^{-4}$		–
$\gamma \eta(1405/1475) \to \gamma \gamma \phi$		$< 8.2 \times 10^{-5}$	CL=95%	–
$\gamma \rho \rho$		$(4.5 \pm 0.8) \times 10^{-3}$		1340
$\gamma \rho \omega$		$< 5.4 \times 10^{-4}$	CL=90%	1338
$\gamma \rho \phi$		$< 8.8 \times 10^{-5}$	CL=90%	1258
$\gamma \eta'(958)$		$(5.13 \pm 0.17) \times 10^{-3}$	S=1.3	1400
$\gamma 2\pi^+ 2\pi^-$		$(2.8 \pm 0.5) \times 10^{-3}$	S=1.9	1517
$\gamma f_2(1270) f_2(1270)$		$(9.5 \pm 1.7) \times 10^{-4}$		878
$\gamma f_2(1270) f_2(1270)$ (non resonant)		$(8.2 \pm 1.9) \times 10^{-4}$		–
$\gamma K^+ K^- \pi^+ \pi^-$		$(2.1 \pm 0.6) \times 10^{-3}$		1407
$\gamma f_4(2050)$		$(2.7 \pm 0.7) \times 10^{-3}$		891
$\gamma \omega \omega$		$(1.61 \pm 0.33) \times 10^{-3}$		1336
$\gamma \eta(1405/1475) \to \gamma \rho^0 \rho^0$		$(1.7 \pm 0.4) \times 10^{-3}$	S=1.3	1223
$\gamma f_2(1270)$		$(1.64 \pm 0.12) \times 10^{-3}$	S=1.3	1286
$\gamma f_0(1370) \to \gamma K \overline{K}$		$(4.2 \pm 1.5) \times 10^{-4}$		–
$\gamma f_0(1710) \to \gamma K \overline{K}$		$(1.00 ^{+0.11}_{-0.09}) \times 10^{-3}$	S=1.5	1075
$\gamma f_0(1710) \to \gamma \pi \pi$		$(3.8 \pm 0.5) \times 10^{-4}$		–
$\gamma f_0(1710) \to \gamma \omega \omega$		$(3.1 \pm 1.0) \times 10^{-4}$		–
$\gamma f_0(1710) \to \gamma \eta \eta$		$(2.4 ^{+1.2}_{-0.7}) \times 10^{-4}$		–
$\gamma \eta$		$(1.104 \pm 0.034) \times 10^{-3}$		1500
$\gamma f_1(1420) \to \gamma K \overline{K} \pi$		$(7.9 \pm 1.3) \times 10^{-4}$		1220
$\gamma f_1(1285)$		$(6.1 \pm 0.8) \times 10^{-4}$		1283
$\gamma f_1(1510) \to \gamma \eta \pi^+ \pi^-$		$(4.5 \pm 1.2) \times 10^{-4}$		–
$\gamma f'_2(1525)$		$(5.7 ^{+0.8}_{-0.5}) \times 10^{-4}$	S=1.5	1173
$\gamma f'_2(1525) \to \gamma \eta \eta$		$(3.4 \pm 1.4) \times 10^{-5}$		–
$\gamma f_2(1640) \to \gamma \omega \omega$		$(2.8 \pm 1.8) \times 10^{-4}$		–
$\gamma f_2(1910) \to \gamma \omega \omega$		$(2.0 \pm 1.4) \times 10^{-4}$		–
$\gamma f_0(1800) \to \gamma \omega \phi$		$(2.5 \pm 0.6) \times 10^{-4}$		–
$\gamma f_2(1810) \to \gamma \eta \eta$		$(5.4 ^{+3.5}_{-2.4}) \times 10^{-5}$		–

$\gamma f_2(1950) \to \gamma K^*(892) \overline{K}^*(892)$		$(7.0 \pm 2.2) \times 10^{-4}$			–
$\gamma K^*(892) \overline{K}^*(892)$		$(4.0 \pm 1.3) \times 10^{-3}$			1266
$\gamma \phi \phi$		$(4.0 \pm 1.2) \times 10^{-4}$		S=2.1	1166
$\gamma p \overline{p}$		$(3.8 \pm 1.0) \times 10^{-4}$			1232
$\gamma \eta(2225)$		$(3.14 {}^{+0.50}_{-0.19}) \times 10^{-4}$			752
$\gamma \eta(1760) \to \gamma \rho^0 \rho^0$		$(1.3 \pm 0.9) \times 10^{-4}$			1048
$\gamma \eta(1760) \to \gamma \omega \omega$		$(1.98 \pm 0.33) \times 10^{-3}$			–
$\gamma X(1835) \to \gamma \pi^+ \pi^- \eta'$		$(2.77 {}^{+0.34}_{-0.40}) \times 10^{-4}$		S=1.1	1006
$\gamma X(1835) \to \gamma p \overline{p}$		$(7.7 {}^{+1.5}_{-0.9}) \times 10^{-5}$			–
$\gamma X(1835) \to \gamma K^0_S K^0_S \eta$		$(3.3 {}^{+2.0}_{-1.3}) \times 10^{-5}$			–
$\gamma X(1840) \to \gamma 3(\pi^+ \pi^-)$		$(2.4 {}^{+0.7}_{-0.8}) \times 10^{-5}$			–
$\gamma (K \overline{K} \pi)\ [J^{PC} = 0^{-+}]$		$(7 \pm 4) \times 10^{-4}$		S=2.1	1442
$\gamma \pi^0$		$(3.49 {}^{+0.33}_{-0.30}) \times 10^{-5}$			1546
$\gamma p \overline{p} \pi^+ \pi^-$		$< 7.9 \times 10^{-4}$		CL=90%	1107
$\gamma \Lambda \overline{\Lambda}$		$< 1.3 \times 10^{-4}$		CL=90%	1074
$\gamma f_0(2100) \to \gamma \eta \eta$		$(1.13 {}^{+0.60}_{-0.30}) \times 10^{-4}$			–
$\gamma f_0(2100) \to \gamma \pi \pi$		$(6.2 \pm 1.0) \times 10^{-4}$			–
$\gamma f_0(2200) \to \gamma K \overline{K}$		$(5.9 \pm 1.3) \times 10^{-4}$			–
$\gamma f_J(2220) \to \gamma \pi \pi$		$< 3.9 \times 10^{-5}$		CL=90%	–
$\gamma f_J(2220) \to \gamma K \overline{K}$		$< 4.1 \times 10^{-5}$		CL=90%	–
$\gamma f_J(2220) \to \gamma p \overline{p}$		$(1.5 \pm 0.8) \times 10^{-5}$			–
$\gamma f_2(2340) \to \gamma \eta \eta$		$(5.6 {}^{+2.4}_{-2.2}) \times 10^{-5}$			–
$\gamma f_0(1500) \to \gamma \pi \pi$		$(1.09 \pm 0.24) \times 10^{-4}$			1183
$\gamma f_0(1500) \to \gamma \eta \eta$		$(1.7 {}^{+0.6}_{-1.4}) \times 10^{-5}$			–
$\gamma A \to \gamma$invisible	[ttaa]	$< 6.3 \times 10^{-6}$		CL=90%	–
$\gamma A^0 \to \gamma \mu^+ \mu^-$	[uuaa]	$< 5 \times 10^{-6}$		CL=90%	–
Dalitz decays					
$\pi^0 e^+ e^-$		$(7.6 \pm 1.4) \times 10^{-7}$			1546
$\eta e^+ e^-$		$(1.16 \pm 0.09) \times 10^{-5}$			1500
$\eta'(958) e^+ e^-$		$(5.81 \pm 0.35) \times 10^{-5}$			1400
Weak decays					
$D^- e^+ \nu_e$ + c.c.		$< 1.2 \times 10^{-5}$		CL=90%	984
$\overline{D}^0 e^+ e^-$ + c.c.		$< 8.5 \times 10^{-8}$		CL=90%	987
$D^-_s e^+ \nu_e$ + c.c.		$< 1.3 \times 10^{-6}$		CL=90%	923
$D^{*-}_s e^+ \nu_e$ + c.c.		$< 1.8 \times 10^{-6}$		CL=90%	828
$D^- \pi^+$ + c.c.		$< 7.5 \times 10^{-5}$		CL=90%	977
$\overline{D}^0 \overline{K}^0$ + c.c.		$< 1.7 \times 10^{-4}$		CL=90%	898
$\overline{D}^0 \overline{K}^{*0}$ + c.c.		$< 2.5 \times 10^{-6}$		CL=90%	670
$D^-_s \pi^+$ + c.c.		$< 1.3 \times 10^{-4}$		CL=90%	915
$D^-_s \rho^+$ + c.c.		$< 1.3 \times 10^{-5}$		CL=90%	663
Charge conjugation (C), Parity (P), Lepton Family number (LF) violating modes					
$\gamma \gamma$	C	$< 2.7 \times 10^{-7}$		CL=90%	1548
$\gamma \phi$	C	$< 1.4 \times 10^{-6}$		CL=90%	1381
$e^\pm \mu^\mp$	LF	$< 1.6 \times 10^{-7}$		CL=90%	1547
$e^\pm \tau^\mp$	LF	$< 8.3 \times 10^{-6}$		CL=90%	1039
$\mu^\pm \tau^\mp$	LF	$< 2.0 \times 10^{-6}$		CL=90%	1035

Other decays

invisible	$< 7 \times 10^{-4}$	CL=90%	–

See Particle Listings for 4 decay modes that have been seen / not seen.

$\chi_{c0}(1P)$

$I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 3414.71 \pm 0.30$ MeV
Full width $\Gamma = 10.8 \pm 0.6$ MeV

$\chi_{c0}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic decays			
$2(\pi^+\pi^-)$	(2.34 ± 0.18) %		1679
$\rho^0\pi^+\pi^-$	$(9.1\ \pm2.9\ )\times10^{-3}$		1607
$f_0(980)f_0(980)$	$(6.6\ \pm2.1\ )\times10^{-4}$		1391
$\pi^+\pi^-\pi^0\pi^0$	$(3.3\ \pm0.4\ )$ %		1680
$\rho^+\pi^-\pi^0$ + c.c.	$(2.9\ \pm0.4\ )$ %		1607
$4\pi^0$	$(3.3\ \pm0.4\ )\times10^{-3}$		1681
$\pi^+\pi^-K^+K^-$	(1.81 ± 0.14) %		1580
$K_0^*(1430)^0\overline{K}_0^*(1430)^0 \to \pi^+\pi^-K^+K^-$	$(9.8\ {}^{+4.0}_{-2.8}\ )\times10^{-4}$		–
$K_0^*(1430)^0\overline{K}_2^*(1430)^0$ + c.c. $\to \pi^+\pi^-K^+K^-$	$(8.0\ {}^{+2.0}_{-2.4}\ )\times10^{-4}$		–
$K_1(1270)^+K^-$ + c.c. $\to \pi^+\pi^-K^+K^-$	$(6.3\ \pm1.9\ )\times10^{-3}$		–
$K_1(1400)^+K^-$ + c.c. $\to \pi^+\pi^-K^+K^-$	$< 2.7\ \times10^{-3}$	CL=90%	–
$f_0(980)f_0(980)$	$(1.6\ {}^{+1.0}_{-0.9}\ )\times10^{-4}$		1391
$f_0(980)f_0(2200)$	$(7.9\ {}^{+2.0}_{-2.5}\ )\times10^{-4}$		584
$f_0(1370)f_0(1370)$	$< 2.7\ \times10^{-4}$	CL=90%	1019
$f_0(1370)f_0(1500)$	$< 1.7\ \times10^{-4}$	CL=90%	921
$f_0(1370)f_0(1710)$	$(6.7\ {}^{+3.5}_{-2.3}\ )\times10^{-4}$		720
$f_0(1500)f_0(1370)$	$< 1.3\ \times10^{-4}$	CL=90%	921
$f_0(1500)f_0(1500)$	$< 5\ \times10^{-5}$	CL=90%	807
$f_0(1500)f_0(1710)$	$< 7\ \times10^{-5}$	CL=90%	557
$K^+K^-\pi^+\pi^-\pi^0$	$(8.6\ \pm0.9\ )\times10^{-3}$		1545
$K_S^0K^\pm\pi^\mp\pi^+\pi^-$	$(4.2\ \pm0.4\ )\times10^{-3}$		1543
$K^+K^-\pi^0\pi^0$	$(5.6\ \pm0.9\ )\times10^{-3}$		1582
$K^+\pi^-\overline{K}^0\pi^0$ + c.c.	(2.49 ± 0.33) %		1581
$\rho^+K^-K^0$ + c.c.	(1.21 ± 0.21) %		1458
$K^*(892)^-K^+\pi^0 \to K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(4.6\ \pm1.2\ )\times10^{-3}$		–
$K_S^0K_S^0\pi^+\pi^-$	$(5.7\ \pm1.1\ )\times10^{-3}$		1579
$K^+K^-\eta\pi^0$	$(3.0\ \pm0.7\ )\times10^{-3}$		1468
$3(\pi^+\pi^-)$	(1.20 ± 0.18) %		1633
$K^+\overline{K}^*(892)^0\pi^-$ + c.c.	$(7.5\ \pm1.6\ )\times10^{-3}$		1523
$K^*(892)^0\overline{K}^*(892)^0$	$(1.7\ \pm0.6\ )\times10^{-3}$		1456
$\pi\pi$	$(8.51\pm0.33)\times10^{-3}$		1702
$\pi^0\eta$	$< 1.8\ \times10^{-4}$		1661
$\pi^0\eta'$	$< 1.1\ \times10^{-3}$		1570
$\pi^0\eta_c$	$< 1.6\ \times10^{-3}$	CL=90%	383
$\eta\eta$	$(3.01\pm0.19)\times10^{-3}$		1617
$\eta\eta'$	$(9.1\ \pm1.1\ )\times10^{-5}$		1521

$\eta' \eta'$	$(2.17 \pm 0.12) \times 10^{-3}$		1413
$\omega \omega$	$(9.7 \pm 1.1) \times 10^{-4}$		1517
$\omega \phi$	$(1.18 \pm 0.22) \times 10^{-4}$		1447
$\omega K^+ K^-$	$(1.94 \pm 0.21) \times 10^{-3}$		1457
$K^+ K^-$	$(6.05 \pm 0.31) \times 10^{-3}$		1634
$K^0_S K^0_S$	$(3.16 \pm 0.17) \times 10^{-3}$		1633
$\pi^+ \pi^- \eta$	$< 2.0 \times 10^{-4}$	CL=90%	1651
$\pi^+ \pi^- \eta'$	$< 4 \times 10^{-4}$	CL=90%	1560
$\overline{K}^0 K^+ \pi^- +$ c.c.	$< 9 \times 10^{-5}$	CL=90%	1610
$K^+ K^- \pi^0$	$< 6 \times 10^{-5}$	CL=90%	1611
$K^+ K^- \eta$	$< 2.3 \times 10^{-4}$	CL=90%	1512
$K^+ K^- K^0_S K^0_S$	$(1.4 \pm 0.5) \times 10^{-3}$		1331
$K^+ K^- K^+ K^-$	$(2.82 \pm 0.29) \times 10^{-3}$		1333
$K^+ K^- \phi$	$(9.7 \pm 2.5) \times 10^{-4}$		1381
$\overline{K}^0 K^+ \pi^- \phi +$ c.c.	$(3.7 \pm 0.6) \times 10^{-3}$		1326
$K^+ K^- \pi^0 \phi$	$(1.90 \pm 0.35) \times 10^{-3}$		1329
$\phi \pi^+ \pi^- \pi^0$	$(1.18 \pm 0.15) \times 10^{-3}$		1525
$\phi \phi$	$(8.0 \pm 0.7) \times 10^{-4}$		1370
$p \overline{p}$	$(2.21 \pm 0.08) \times 10^{-4}$		1426
$p \overline{p} \pi^0$	$(7.0 \pm 0.7) \times 10^{-4}$	S=1.3	1379
$p \overline{p} \eta$	$(3.5 \pm 0.4) \times 10^{-4}$		1187
$p \overline{p} \omega$	$(5.2 \pm 0.6) \times 10^{-4}$		1043
$p \overline{p} \phi$	$(6.0 \pm 1.4) \times 10^{-5}$		876
$p \overline{p} \pi^+ \pi^-$	$(2.1 \pm 0.7) \times 10^{-3}$	S=1.4	1320
$p \overline{p} \pi^0 \pi^0$	$(1.04 \pm 0.28) \times 10^{-3}$		1324
$p \overline{p} K^+ K^-$ (non-resonant)	$(1.22 \pm 0.26) \times 10^{-4}$		890
$p \overline{p} K^0_S K^0_S$	$< 8.8 \times 10^{-4}$	CL=90%	884
$p \overline{n} \pi^-$	$(1.27 \pm 0.11) \times 10^{-3}$		1376
$\overline{p} n \pi^+$	$(1.37 \pm 0.12) \times 10^{-3}$		1376
$p \overline{n} \pi^- \pi^0$	$(2.34 \pm 0.21) \times 10^{-3}$		1321
$\overline{p} n \pi^+ \pi^0$	$(2.21 \pm 0.18) \times 10^{-3}$		1321
$\Lambda \overline{\Lambda}$	$(3.27 \pm 0.24) \times 10^{-4}$		1292
$\Lambda \overline{\Lambda} \pi^+ \pi^-$	$(1.18 \pm 0.13) \times 10^{-3}$		1153
$\Lambda \overline{\Lambda} \pi^+ \pi^-$ (non-resonant)	$< 5 \times 10^{-4}$	CL=90%	1153
$\Sigma(1385)^+ \overline{\Lambda} \pi^- +$ c.c.	$< 5 \times 10^{-4}$	CL=90%	1083
$\Sigma(1385)^- \overline{\Lambda} \pi^+ +$ c.c.	$< 5 \times 10^{-4}$	CL=90%	1083
$K^+ \overline{p} \Lambda +$ c.c.	$(1.25 \pm 0.12) \times 10^{-3}$	S=1.3	1132
$K^+ \overline{p} \Lambda(1520) +$ c.c.	$(2.9 \pm 0.7) \times 10^{-4}$		858
$\Lambda(1520) \overline{\Lambda}(1520)$	$(3.1 \pm 1.2) \times 10^{-4}$		779
$\Sigma^0 \overline{\Sigma}^0$	$(4.5 \pm 0.4) \times 10^{-4}$		1222
$\Sigma^+ \overline{\Sigma}^-$	$(4.0 \pm 0.7) \times 10^{-4}$	S=1.7	1225
$\Sigma(1385)^+ \overline{\Sigma}(1385)^-$	$(1.6 \pm 0.6) \times 10^{-4}$		1001
$\Sigma(1385)^- \overline{\Sigma}(1385)^+$	$(2.3 \pm 0.7) \times 10^{-4}$		1001
$K^- \Lambda \Xi^+ +$ c.c.	$(1.94 \pm 0.35) \times 10^{-4}$		873
$\Xi^0 \overline{\Xi}^0$	$(3.1 \pm 0.8) \times 10^{-4}$		1089
$\Xi^- \overline{\Xi}^+$	$(4.8 \pm 0.7) \times 10^{-4}$		1081
$\eta_c \pi^+ \pi^-$	$< 7 \times 10^{-4}$	CL=90%	307
Radiative decays			
$\gamma J/\psi(1S)$	(1.40 ± 0.05) %		303
$\gamma \rho^0$	$< 9 \times 10^{-6}$	CL=90%	1619
$\gamma \omega$	$< 8 \times 10^{-6}$	CL=90%	1618
$\gamma \phi$	$< 6 \times 10^{-6}$	CL=90%	1555
$\gamma \gamma$	$(2.04 \pm 0.09) \times 10^{-4}$		1707
$e^+ e^- J/\psi(1S)$	$(1.54 \pm 0.33) \times 10^{-4}$		303

$\chi_{c1}(1P)$

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 3510.67 \pm 0.05$ MeV (S = 1.2)
Full width $\Gamma = 0.84 \pm 0.04$ MeV

$\chi_{c1}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic decays			
$3(\pi^+\pi^-)$	$(5.8 \pm 1.4) \times 10^{-3}$	S=1.2	1683
$2(\pi^+\pi^-)$	$(7.6 \pm 2.6) \times 10^{-3}$		1728
$\pi^+\pi^-\pi^0\pi^0$	(1.19 ± 0.15) %		1729
$\rho^+\pi^-\pi^0$ + c.c.	(1.45 ± 0.24) %		1658
$\rho^0\pi^+\pi^-$	$(3.9 \pm 3.5) \times 10^{-3}$		1657
$4\pi^0$	$(5.4 \pm 0.8) \times 10^{-4}$		1729
$\pi^+\pi^-K^+K^-$	$(4.5 \pm 1.0) \times 10^{-3}$		1632
$K^+K^-\pi^0\pi^0$	$(1.12\pm 0.27) \times 10^{-3}$		1634
$K^+K^-\pi^+\pi^-\pi^0$	(1.15 ± 0.13) %		1598
$K^0_S K^\pm\pi^\mp\pi^+\pi^-$	$(7.5 \pm 0.8) \times 10^{-3}$		1596
$K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(8.6 \pm 1.4) \times 10^{-3}$		1632
$\rho^-K^+\overline{K}^0$ + c.c.	$(5.0 \pm 1.2) \times 10^{-3}$		1514
$K^*(892)^0\overline{K}^0\pi^0 \to K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(2.3 \pm 0.6) \times 10^{-3}$		–
$K^+K^-\eta\pi^0$	$(1.12\pm 0.34) \times 10^{-3}$		1523
$\pi^+\pi^-K^0_S K^0_S$	$(6.9 \pm 2.9) \times 10^{-4}$		1630
$K^+K^-\eta$	$(3.2 \pm 1.0) \times 10^{-4}$		1566
$\overline{K}^0K^+\pi^-$ + c.c.	$(7.0 \pm 0.6) \times 10^{-3}$		1661
$K^*(892)^0\overline{K}^0$ + c.c.	$(10 \pm 4) \times 10^{-4}$		1602
$K^*(892)^+K^-$ + c.c.	$(1.4 \pm 0.6) \times 10^{-3}$		1602
$K^*_J(1430)^0\overline{K}^0$ + c.c. $\to K^0_S K^+\pi^-$ + c.c.	$< 8 \times 10^{-4}$	CL=90%	–
$K^*_J(1430)^+K^-$ + c.c. $\to K^0_S K^+\pi^-$ + c.c.	$< 2.1 \times 10^{-3}$	CL=90%	–
$K^+K^-\pi^0$	$(1.81\pm 0.24) \times 10^{-3}$		1662
$\eta\pi^+\pi^-$	$(4.62\pm 0.23) \times 10^{-3}$		1701
$a_0(980)^+\pi^-$ + c.c. $\to \eta\pi^+\pi^-$	$(3.2 \pm 0.4) \times 10^{-3}$	S=2.2	–
$a_2(1320)^+\pi^-$ + c.c. $\to \eta\pi^+\pi^-$	$(1.76\pm 0.24) \times 10^{-4}$		–
$a_2(1700)^+\pi^-$ + c.c. $\to \eta\pi^+\pi^-$	$(4.6 \pm 0.7) \times 10^{-5}$		–
$f_2(1270)\eta \to \eta\pi^+\pi^-$	$(3.5 \pm 0.6) \times 10^{-4}$		–
$f_4(2050)\eta \to \eta\pi^+\pi^-$	$(2.5 \pm 0.9) \times 10^{-5}$		–
$\pi_1(1400)^+\pi^-$ + c.c. $\to \eta\pi^+\pi^-$	$< 5 \times 10^{-5}$	CL=90%	–
$\pi_1(1600)^+\pi^-$ + c.c. $\to \eta\pi^+\pi^-$	$< 1.5 \times 10^{-5}$	CL=90%	–
$\pi_1(2015)^+\pi^-$ + c.c. $\to \eta\pi^+\pi^-$	$< 8 \times 10^{-6}$	CL=90%	–
$f_2(1270)\eta$	$(6.7 \pm 1.1) \times 10^{-4}$		1467
$\pi^+\pi^-\eta'$	$(2.2 \pm 0.4) \times 10^{-3}$		1612
$K^+K^-\eta'(958)$	$(8.8 \pm 0.9) \times 10^{-4}$		1461
$K^*_0(1430)^+K^-$ + c.c.	$(6.4 {}^{+2.2}_{-2.8}) \times 10^{-4}$		–
$f_0(980)\eta'(958)$	$(1.6 {}^{+1.4}_{-0.7}) \times 10^{-4}$		1460
$f_0(1710)\eta'(958)$	$(7 {}^{+7}_{-5}) \times 10^{-5}$		1106
$f'_2(1525)\eta'(958)$	$(9 \pm 6) \times 10^{-5}$		1225
$\pi^0 f_0(980) \to \pi^0\pi^+\pi^-$	$< 6 \times 10^{-6}$	CL=90%	–
$K^+\overline{K}^*(892)^0\pi^-$ + c.c.	$(3.2 \pm 2.1) \times 10^{-3}$		1577
$K^*(892)^0\overline{K}^*(892)^0$	$(1.4 \pm 0.4) \times 10^{-3}$		1512

$K^+K^-K^0_S K^0_S$	< 4	$\times 10^{-4}$	CL=90%	1390
$K^+K^-K^+K^-$	(5.4 ± 1.1)	$\times 10^{-4}$		1393
$K^+K^-\phi$	(4.1 ± 1.5)	$\times 10^{-4}$		1440
$\overline{K}^0 K^+\pi^-\phi$+ c.c.	(3.3 ± 0.5)	$\times 10^{-3}$		1387
$K^+K^-\pi^0\phi$	(1.62 ± 0.30)	$\times 10^{-3}$		1390
$\phi\pi^+\pi^-\pi^0$	(7.5 ± 1.0)	$\times 10^{-4}$		1578
$\omega\omega$	(5.7 ± 0.7)	$\times 10^{-4}$		1571
ωK^+K^-	(7.8 ± 0.9)	$\times 10^{-4}$		1513
$\omega\phi$	(2.1 ± 0.6)	$\times 10^{-5}$		1503
$\phi\phi$	(4.2 ± 0.5)	$\times 10^{-4}$		1429
$p\overline{p}$	(7.60 ± 0.34)	$\times 10^{-5}$		1484
$p\overline{p}\pi^0$	(1.55 ± 0.18)	$\times 10^{-4}$		1438
$p\overline{p}\eta$	(1.45 ± 0.25)	$\times 10^{-4}$		1254
$p\overline{p}\omega$	(2.12 ± 0.31)	$\times 10^{-4}$		1117
$p\overline{p}\phi$	< 1.7	$\times 10^{-5}$	CL=90%	962
$p\overline{p}\pi^+\pi^-$	(5.0 ± 1.9)	$\times 10^{-4}$		1381
$p\overline{p}K^+K^-$ (non-resonant)	(1.27 ± 0.22)	$\times 10^{-4}$		974
$p\overline{p}K^0_S K^0_S$	< 4.5	$\times 10^{-4}$	CL=90%	968
$p\overline{n}\pi^-$	(3.8 ± 0.5)	$\times 10^{-4}$		1435
$\overline{p}n\pi^+$	(3.9 ± 0.5)	$\times 10^{-4}$		1435
$p\overline{n}\pi^-\pi^0$	(1.03 ± 0.12)	$\times 10^{-3}$		1383
$\overline{p}n\pi^+\pi^0$	(1.01 ± 0.12)	$\times 10^{-3}$		1383
$\Lambda\overline{\Lambda}$	(1.14 ± 0.11)	$\times 10^{-4}$		1355
$\Lambda\overline{\Lambda}\pi^+\pi^-$	(2.9 ± 0.5)	$\times 10^{-4}$		1223
$\Lambda\overline{\Lambda}\pi^+\pi^-$ (non-resonant)	(2.5 ± 0.6)	$\times 10^{-4}$		1223
$\Sigma(1385)^+\overline{\Lambda}\pi^-$ + c.c.	< 1.3	$\times 10^{-4}$	CL=90%	1157
$\Sigma(1385)^-\overline{\Lambda}\pi^+$ + c.c.	< 1.3	$\times 10^{-4}$	CL=90%	1157
$K^+\overline{p}\Lambda$	(4.1 ± 0.4)	$\times 10^{-4}$	S=1.2	1203
$K^+\overline{p}\Lambda(1520)$+ c.c.	(1.7 ± 0.4)	$\times 10^{-4}$		950
$\Lambda(1520)\overline{\Lambda}(1520)$	< 9	$\times 10^{-5}$	CL=90%	879
$\Sigma^0\overline{\Sigma}^0$	< 4	$\times 10^{-5}$	CL=90%	1288
$\Sigma^+\overline{\Sigma}^-$	< 6	$\times 10^{-5}$	CL=90%	1291
$\Sigma(1385)^+\overline{\Sigma}(1385)^-$	< 9	$\times 10^{-5}$	CL=90%	1081
$\Sigma(1385)^-\overline{\Sigma}(1385)^+$	< 5	$\times 10^{-5}$	CL=90%	1081
$K^-\Lambda\overline{\Xi}^+$ + c.c.	(1.35 ± 0.24)	$\times 10^{-4}$		963
$\Xi^0\overline{\Xi}^0$	< 6	$\times 10^{-5}$	CL=90%	1163
$\Xi^-\overline{\Xi}^+$	(8.0 ± 2.1)	$\times 10^{-5}$		1155
$\pi^+\pi^-$ + K^+K^-	< 2.1	$\times 10^{-3}$		–
$K^0_S K^0_S$	< 6	$\times 10^{-5}$	CL=90%	1683
$\eta_c\pi^+\pi^-$	< 3.2	$\times 10^{-3}$	CL=90%	413

Radiative decays

$\gamma J/\psi(1S)$	(34.3 ± 1.0)	%		389
$\gamma\rho^0$	(2.16 ± 0.17)	$\times 10^{-4}$		1670
$\gamma\omega$	(6.8 ± 0.8)	$\times 10^{-5}$		1668
$\gamma\phi$	(2.4 ± 0.5)	$\times 10^{-5}$		1607
$\gamma\gamma$	< 6.3	$\times 10^{-6}$	CL=90%	1755
$e^+e^-J/\psi(1S)$	(3.65 ± 0.25)	$\times 10^{-3}$		389

$h_c(1P)$

$I^G(J^{PC}) = ?^?(1^{+-})$

Mass $m = 3525.38 \pm 0.11$ MeV
Full width $\Gamma = 0.7 \pm 0.4$ MeV

$h_c(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$p\overline{p}$	$< 1.5 \times 10^{-4}$	90%	1492
$\pi^+\pi^-\pi^0$	$< 2.2 \times 10^{-3}$		1749
$2\pi^+2\pi^-\pi^0$	$(2.2^{+0.8}_{-0.7})$ %		1716
$3\pi^+3\pi^-\pi^0$	< 2.9 %		1661
Radiative decays			
$\gamma\eta$	$(4.7\pm2.1) \times 10^{-4}$		1720
$\gamma\eta'(958)$	$(1.5\pm0.4) \times 10^{-3}$		1633
$\gamma\eta_c(1S)$	(51 ± 6) %		500

See Particle Listings for 1 decay modes that have been seen / not seen.

$\chi_{c2}(1P)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 3556.17 \pm 0.07$ MeV
Full width $\Gamma = 1.97 \pm 0.09$ MeV

$\chi_{c2}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
Hadronic decays			
$2(\pi^+\pi^-)$	(1.02 ± 0.09) %		1751
$\pi^+\pi^-\pi^0\pi^0$	(1.83 ± 0.23) %		1752
$\rho^+\pi^-\pi^0$ + c.c.	(2.19 ± 0.34) %		1682
$4\pi^0$	$(1.11\pm0.15) \times 10^{-3}$		1752
$K^+K^-\pi^0\pi^0$	$(2.1 \pm0.4) \times 10^{-3}$		1658
$K^+\pi^-\overline{K}^0\pi^0$ + c.c.	(1.38 ± 0.20) %		1657
$\rho^-K^+\overline{K}^0$ + c.c.	$(4.1 \pm1.2) \times 10^{-3}$		1540
$K^*(892)^0K^-\pi^+ \to K^-\pi^+K^0\pi^0$ + c.c.	$(2.9 \pm0.8) \times 10^{-3}$		–
$K^*(892)^0\overline{K}^0\pi^0 \to K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(3.8 \pm0.9) \times 10^{-3}$		–
$K^*(892)^-K^+\pi^0 \to K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(3.7 \pm0.8) \times 10^{-3}$		–
$K^*(892)^+\overline{K}^0\pi^- \to K^+\pi^-\overline{K}^0\pi^0$ + c.c.	$(2.9 \pm0.8) \times 10^{-3}$		–
$K^+K^-\eta\pi^0$	$(1.3 \pm0.4) \times 10^{-3}$		1549
$K^+K^-\pi^+\pi^-$	$(8.4 \pm0.9) \times 10^{-3}$		1656
$K^+K^-\pi^+\pi^-\pi^0$	(1.17 ± 0.13) %		1623
$K^0_SK^\pm\pi^\mp\pi^+\pi^-$	$(7.3 \pm0.8) \times 10^{-3}$		1621
$K^+\overline{K}^*(892)^0\pi^-$ + c.c.	$(2.1 \pm1.1) \times 10^{-3}$		1602
$K^*(892)^0\overline{K}^*(892)^0$	$(2.3 \pm0.4) \times 10^{-3}$		1538
$3(\pi^+\pi^-)$	$(8.6 \pm1.8) \times 10^{-3}$		1707
$\phi\phi$	$(1.06\pm0.09) \times 10^{-3}$		1457
$\omega\omega$	$(8.4 \pm1.0) \times 10^{-4}$		1597
ωK^+K^-	$(7.3 \pm0.9) \times 10^{-4}$		1540
$\pi\pi$	$(2.23\pm0.09) \times 10^{-3}$		1773
$\rho^0\pi^+\pi^-$	$(3.7 \pm1.6) \times 10^{-3}$		1682
$\pi^+\pi^-\pi^0$ (non-resonant)	$(2.0 \pm0.4) \times 10^{-5}$		1765
$\rho(770)^\pm\pi^\mp$	$(6 \pm4) \times 10^{-6}$		–

$\pi^+\pi^-\eta$	$(4.8\ \pm1.3\ )\times10^{-4}$		1724
$\pi^+\pi^-\eta'$	$(5.0\ \pm1.8\ )\times10^{-4}$		1636
$\eta\eta$	$(5.4\ \pm0.4\ )\times10^{-4}$		1692
K^+K^-	$(1.01\pm0.06)\times10^{-3}$		1708
$K^0_S K^0_S$	$(5.2\ \pm0.4\ )\times10^{-4}$		1707
$K^*(892)^\pm K^\mp$	$(1.44\pm0.21)\times10^{-4}$		1627
$K^*(892)^0\overline{K}^0$ + c.c.	$(1.24\pm0.27)\times10^{-4}$		1627
$K^*_2(1430)^\pm K^\mp$	$(1.48\pm0.12)\times10^{-3}$		–
$K^*_2(1430)^0\overline{K}^0$ + c.c.	$(1.24\pm0.17)\times10^{-3}$		1444
$K^*_3(1780)^\pm K^\mp$	$(5.2\ \pm0.8\ )\times10^{-4}$		–
$K^*_3(1780)^0\overline{K}^0$ + c.c.	$(5.6\ \pm2.1\ )\times10^{-4}$		1276
$a_2(1320)^0\pi^0$	$(1.29\pm0.34)\times10^{-3}$		–
$a_2(1320)^\pm\pi^\mp$	$(1.8\ \pm0.6\ )\times10^{-3}$		1530
$\overline{K}^0K^+\pi^-$ + c.c.	$(1.28\pm0.18)\times10^{-3}$		1685
$K^+K^-\pi^0$	$(3.0\ \pm0.8\ )\times10^{-4}$		1686
$K^+K^-\eta$	$<3.2\times10^{-4}$	90%	1592
$K^+K^-\eta'(958)$	$(1.94\pm0.34)\times10^{-4}$		1488
$\eta\eta'$	$(2.2\ \pm0.5\ )\times10^{-5}$		1600
$\eta'\eta'$	$(4.6\ \pm0.6\ )\times10^{-5}$		1498
$\pi^+\pi^-K^0_S K^0_S$	$(2.2\ \pm0.5\ )\times10^{-3}$		1655
$K^+K^-K^0_S K^0_S$	$<4\times10^{-4}$	90%	1418
$K^+K^-K^+K^-$	$(1.65\pm0.20)\times10^{-3}$		1421
$K^+K^-\phi$	$(1.42\pm0.29)\times10^{-3}$		1468
$\overline{K}^0K^+\pi^-\phi$+ c.c.	$(4.8\ \pm0.7\ )\times10^{-3}$		1416
$K^+K^-\pi^0\phi$	$(2.7\ \pm0.5\ )\times10^{-3}$		1419
$\phi\pi^+\pi^-\pi^0$	$(9.3\ \pm1.2\ )\times10^{-4}$		1603
$p\overline{p}$	$(7.33\pm0.33)\times10^{-5}$		1510
$p\overline{p}\pi^0$	$(4.7\ \pm0.4\ )\times10^{-4}$		1465
$p\overline{p}\eta$	$(1.74\pm0.25)\times10^{-4}$		1285
$p\overline{p}\omega$	$(3.6\ \pm0.4\ )\times10^{-4}$		1152
$p\overline{p}\phi$	$(2.8\ \pm0.9\ )\times10^{-5}$		1002
$p\overline{p}\pi^+\pi^-$	$(1.32\pm0.34)\times10^{-3}$		1410
$p\overline{p}\pi^0\pi^0$	$(7.8\ \pm2.3\ )\times10^{-4}$		1414
$p\overline{p}K^+K^-$ (non-resonant)	$(1.91\pm0.32)\times10^{-4}$		1013
$p\overline{p}K^0_S K^0_S$	$<7.9\times10^{-4}$	90%	1007
$p\overline{n}\pi^-$	$(8.5\ \pm0.9\ )\times10^{-4}$		1463
$\overline{p}n\pi^+$	$(8.9\ \pm0.8\ )\times10^{-4}$		1463
$p\overline{n}\pi^-\pi^0$	$(2.17\pm0.18)\times10^{-3}$		1411
$\overline{p}n\pi^+\pi^0$	$(2.11\pm0.18)\times10^{-3}$		1411
$\Lambda\overline{\Lambda}$	$(1.84\pm0.15)\times10^{-4}$		1384
$\Lambda\overline{\Lambda}\pi^+\pi^-$	$(1.25\pm0.15)\times10^{-3}$		1255
$\Lambda\overline{\Lambda}\pi^+\pi^-$ (non-resonant)	$(6.6\ \pm1.5\ )\times10^{-4}$		1255
$\Sigma(1385)^+\overline{\Lambda}\pi^-$ + c.c.	$<4\times10^{-4}$	90%	1192
$\Sigma(1385)^-\overline{\Lambda}\pi^+$ + c.c.	$<6\times10^{-4}$	90%	1192
$K^+\overline{p}\Lambda$ + c.c.	$(7.8\ \pm0.5\ )\times10^{-4}$		1236
$K^+\overline{p}\Lambda(1520)$ + c.c.	$(2.8\ \pm0.7\ )\times10^{-4}$		992
$\Lambda(1520)\overline{\Lambda}(1520)$	$(4.6\ \pm1.5\ )\times10^{-4}$		923
$\Sigma^0\overline{\Sigma}^0$	$<6\times10^{-5}$	90%	1319
$\Sigma^+\overline{\Sigma}^-$	$<7\times10^{-5}$	90%	1322
$\Sigma(1385)^+\overline{\Sigma}(1385)^-$	$<1.6\times10^{-4}$	90%	1118
$\Sigma(1385)^-\overline{\Sigma}(1385)^+$	$<8\times10^{-5}$	90%	1118
$K^-\Lambda\overline{\Xi}^+$ + c.c.	$(1.76\pm0.32)\times10^{-4}$		1004
$\Xi^0\overline{\Xi}^0$	$<1.0\times10^{-4}$	90%	1197
$\Xi^-\overline{\Xi}^+$	$(1.42\pm0.32)\times10^{-4}$		1189

$J/\psi(1S)\pi^+\pi^-\pi^0$	$<\ 1.5$ %		90%	185
$\pi^0\eta_c$	$<\ 3.2\ \times 10^{-3}$		90%	511
$\eta_c(1S)\pi^+\pi^-$	$<\ 5.4\ \times 10^{-3}$		90%	459
Radiative decays				
$\gamma J/\psi(1S)$	$(19.0\ \pm 0.5\ )$ %			430
$\gamma\rho^0$	$<\ 1.9\ \times 10^{-5}$		90%	1694
$\gamma\omega$	$<\ 6\ \times 10^{-6}$		90%	1692
$\gamma\phi$	$<\ 7\ \times 10^{-6}$		90%	1632
$\gamma\gamma$	$(\ 2.85\pm0.10) \times 10^{-4}$			1778
$e^+e^-J/\psi(1S)$	$(\ 2.37\pm0.16) \times 10^{-3}$			430

$\eta_c(2S)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Quantum numbers are quark model predictions.

Mass $m = 3637.6 \pm 1.2$ MeV (S = 1.2)
Full width $\Gamma = 11.3^{+3.2}_{-2.9}$ MeV

$\eta_c(2S)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\overline{K}\pi$	$(\ 1.9\pm1.2)$ %		1729
$K\overline{K}\eta$	$(\ 5\ \ \pm4\ \ ) \times 10^{-3}$		1637
$K^+K^-\pi^+\pi^-\pi^0$	$(\ 1.4\pm1.0)$ %		1667
$\gamma\gamma$	$(\ 1.9\pm1.3) \times 10^{-4}$		1819
$\gamma J/\psi(1S)$	$<\ 1.4$ %	90%	500
$\pi^+\pi^-\eta_c(1S)$	< 25 %	90%	538

See Particle Listings for 13 decay modes that have been seen / not seen.

$\psi(2S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 3686.097 \pm 0.025$ MeV (S = 2.6)
Full width $\Gamma = 294 \pm 8$ keV
$\Gamma_{ee} = 2.33 \pm 0.04$ keV

$\psi(2S)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
hadrons	$(97.85\ \pm0.13\ )$ %		–
virtual$\gamma \to$ hadrons	$(\ 1.73\ \pm0.14\ )$ %	S=1.5	–
ggg	$(10.6\ \ \pm1.6\ \ )$ %		–
γgg	$(\ 1.03\ \pm0.29\ )$ %		–
light hadrons	$(15.4\ \ \pm1.5\ \ )$ %		–
e^+e^-	$(\ 7.93\ \pm0.17\ ) \times 10^{-3}$		1843
$\mu^+\mu^-$	$(\ 8.0\ \ \pm0.6\ \ ) \times 10^{-3}$		1840
$\tau^+\tau^-$	$(\ 3.1\ \ \pm0.4\ \ ) \times 10^{-3}$		489
Decays into $J/\psi(1S)$ and anything			
$J/\psi(1S)$anything	$(61.4\ \ \pm0.6\ \ )$ %		–
$J/\psi(1S)$neutrals	$(25.37\ \pm0.32\ )$ %		–
$J/\psi(1S)\pi^+\pi^-$	$(34.67\ \pm0.30\ )$ %		477
$J/\psi(1S)\pi^0\pi^0$	$(18.23\ \pm0.31\ )$ %		481
$J/\psi(1S)\eta$	$(\ 3.37\ \pm0.05\ )$ %		199
$J/\psi(1S)\pi^0$	$(\ 1.268\pm0.032) \times 10^{-3}$		528

Hadronic decays

$\pi^0 h_c(1P)$	$(8.6 \pm 1.3) \times 10^{-4}$		85
$3(\pi^+\pi^-)\pi^0$	$(3.5 \pm 1.6) \times 10^{-3}$		1746
$2(\pi^+\pi^-)\pi^0$	$(2.9 \pm 1.0) \times 10^{-3}$	S=4.7	1799
$\rho a_2(1320)$	$(2.6 \pm 0.9) \times 10^{-4}$		1500
$p\overline{p}$	$(2.88 \pm 0.10) \times 10^{-4}$		1586
$\Delta^{++}\overline{\Delta}^{--}$	$(1.28 \pm 0.35) \times 10^{-4}$		1371
$\Lambda\overline{\Lambda}\pi^0$	$< 2.9 \times 10^{-6}$	CL=90%	1412
$\Lambda\overline{\Lambda}\eta$	$(2.5 \pm 0.4) \times 10^{-5}$		1197
$\Lambda\overline{p}K^+$	$(1.00 \pm 0.14) \times 10^{-4}$		1327
$\Lambda\overline{p}K^+\pi^+\pi^-$	$(1.8 \pm 0.4) \times 10^{-4}$		1167
$\Lambda\overline{\Lambda}\pi^+\pi^-$	$(2.8 \pm 0.6) \times 10^{-4}$		1346
$\Lambda\overline{\Lambda}$	$(3.81 \pm 0.13) \times 10^{-4}$	S=1.4	1467
$\Lambda\overline{\Sigma}^+\pi^-$ + c.c.	$(1.40 \pm 0.13) \times 10^{-4}$		1376
$\Lambda\overline{\Sigma}^-\pi^+$ + c.c.	$(1.54 \pm 0.14) \times 10^{-4}$		1379
$\Lambda\overline{\Sigma}^0$	$(1.23 \pm 0.24) \times 10^{-5}$		1437
$\Sigma^0\overline{p}K^+$ + c.c.	$(1.67 \pm 0.18) \times 10^{-5}$		1291
$\Sigma^+\overline{\Sigma}^-$	$(2.32 \pm 0.12) \times 10^{-4}$		1408
$\Sigma^0\overline{\Sigma}^0$	$(2.35 \pm 0.09) \times 10^{-4}$	S=1.1	1405
$\Sigma(1385)^+\overline{\Sigma}(1385)^-$	$(8.5 \pm 0.7) \times 10^{-5}$		1218
$\Sigma(1385)^-\overline{\Sigma}(1385)^+$	$(8.5 \pm 0.8) \times 10^{-5}$		1218
$\Sigma(1385)^0\overline{\Sigma}(1385)^0$	$(6.9 \pm 0.7) \times 10^{-5}$		1218
$\Xi^-\overline{\Xi}^+$	$(2.87 \pm 0.11) \times 10^{-4}$	S=1.1	1284
$\Xi^0\overline{\Xi}^0$	$(2.3 \pm 0.4) \times 10^{-4}$	S=4.2	1291
$\Xi(1530)^0\overline{\Xi}(1530)^0$	$(5.2 {}^{+3.2}_{-1.2}) \times 10^{-5}$		1025
$K^-\Lambda\overline{\Xi}^+$ + c.c.	$(3.9 \pm 0.4) \times 10^{-5}$		1114
$\Xi(1690)^-\overline{\Xi}^+ \to K^-\Lambda\overline{\Xi}^+$ + c.c.	$(5.2 \pm 1.6) \times 10^{-6}$		–
$\Xi(1820)^-\overline{\Xi}^+ \to K^-\Lambda\overline{\Xi}^+$ + c.c.	$(1.20 \pm 0.32) \times 10^{-5}$		–
$K^-\Sigma^0\overline{\Xi}^+$ + c.c.	$(3.7 \pm 0.4) \times 10^{-5}$		1060
$\Omega^-\overline{\Omega}^+$	$(5.2 \pm 0.4) \times 10^{-5}$		774
$\pi^0 p\overline{p}$	$(1.53 \pm 0.07) \times 10^{-4}$		1543
$N(940)\overline{p}$+ c.c. $\to \pi^0 p\overline{p}$	$(6.4 {}^{+1.8}_{-1.3}) \times 10^{-5}$		–
$N(1440)\overline{p}$+ c.c. $\to \pi^0 p\overline{p}$	$(7.3 {}^{+1.7}_{-1.5}) \times 10^{-5}$	S=2.5	–
$N(1520)\overline{p}$+ c.c. $\to \pi^0 p\overline{p}$	$(6.4 {}^{+2.3}_{-1.8}) \times 10^{-6}$		–
$N(1535)\overline{p}$+ c.c. $\to \pi^0 p\overline{p}$	$(2.5 \pm 1.0) \times 10^{-5}$		–
$N(1650)\overline{p}$+ c.c. $\to \pi^0 p\overline{p}$	$(3.8 {}^{+1.4}_{-1.7}) \times 10^{-5}$		–
$N(1720)\overline{p}$+ c.c. $\to \pi^0 p\overline{p}$	$(1.79 {}^{+0.26}_{-0.70}) \times 10^{-5}$		–
$N(2300)\overline{p}$+ c.c. $\to \pi^0 p\overline{p}$	$(2.6 {}^{+1.2}_{-0.7}) \times 10^{-5}$		–
$N(2570)\overline{p}$+ c.c. $\to \pi^0 p\overline{p}$	$(2.13 {}^{+0.40}_{-0.31}) \times 10^{-5}$		–
$\pi^0 f_0(2100) \to \pi^0 p\overline{p}$	$(1.1 \pm 0.4) \times 10^{-5}$		–
$\eta p\overline{p}$	$(6.0 \pm 0.4) \times 10^{-5}$		1373
$\eta f_0(2100) \to \eta p\overline{p}$	$(1.2 \pm 0.4) \times 10^{-5}$		–
$N(1535)\overline{p} \to \eta p\overline{p}$	$(4.4 \pm 0.7) \times 10^{-5}$		–
$\omega p\overline{p}$	$(6.9 \pm 2.1) \times 10^{-5}$		1247
$\phi p\overline{p}$	$< 2.4 \times 10^{-5}$	CL=90%	1109
$\pi^+\pi^- p\overline{p}$	$(6.0 \pm 0.4) \times 10^{-4}$		1491
$p\overline{n}\pi^-$ or c.c.	$(2.48 \pm 0.17) \times 10^{-4}$		–
$p\overline{n}\pi^-\pi^0$	$(3.2 \pm 0.7) \times 10^{-4}$		1492
$2(\pi^+\pi^-\pi^0)$	$(4.8 \pm 1.5) \times 10^{-3}$		1776

$\eta\pi^+\pi^-$	$<$ 1.6		$\times 10^{-4}$	CL=90%	1791
$\eta\pi^+\pi^-\pi^0$	(9.5	± 1.7	) $\times 10^{-4}$		1778
$2(\pi^+\pi^-)\eta$	(1.2	± 0.6	) $\times 10^{-3}$		1758
$\eta'\pi^+\pi^-\pi^0$	(4.5	± 2.1	) $\times 10^{-4}$		1692
$\omega\pi^+\pi^-$	(7.3	± 1.2	) $\times 10^{-4}$	S=2.1	1748
$b_1^\pm\pi^\mp$	(4.0	± 0.6	) $\times 10^{-4}$	S=1.1	1635
$b_1^0\pi^0$	(2.4	± 0.6	) $\times 10^{-4}$		–
$\omega f_2(1270)$	(2.2	± 0.4	) $\times 10^{-4}$		1515
$\pi^0\pi^0 K^+ K^-$	(2.6	± 1.3	) $\times 10^{-4}$		1728
$\pi^+\pi^- K^+ K^-$	(7.3	± 0.5	) $\times 10^{-4}$		1726
$\pi^0\pi^0 K_S^0 K_L^0$	(1.3	± 0.5	) $\times 10^{-3}$		1726
$\rho^0 K^+ K^-$	(2.2	± 0.4	) $\times 10^{-4}$		1616
$K^*(892)^0\overline{K}_2^*(1430)^0$	(1.9	± 0.5	) $\times 10^{-4}$		1418
$K^+K^-\pi^+\pi^-\eta$	(1.3	± 0.7	) $\times 10^{-3}$		1574
$K^+K^- 2(\pi^+\pi^-)\pi^0$	(1.00	± 0.31	) $\times 10^{-3}$		1611
$K^+K^- 2(\pi^+\pi^-)$	(1.9	± 0.9	) $\times 10^{-3}$		1654
$K_1(1270)^\pm K^\mp$	(1.00	± 0.28	) $\times 10^{-3}$		1581
$K_S^0 K_S^0 \pi^+\pi^-$	(2.2	± 0.4	) $\times 10^{-4}$		1724
$\rho^0 p\overline{p}$	(5.0	± 2.2	) $\times 10^{-5}$		1252
$K^+\overline{K}^*(892)^0\pi^-$ + c.c.	(6.7	± 2.5	) $\times 10^{-4}$		1674
$2(\pi^+\pi^-)$	(2.4	± 0.6	) $\times 10^{-4}$	S=2.2	1817
$\rho^0\pi^+\pi^-$	(2.2	± 0.6	) $\times 10^{-4}$	S=1.4	1750
$K^+K^-\pi^+\pi^-\pi^0$	(1.26	± 0.09	) $\times 10^{-3}$		1694
$\omega f_0(1710) \rightarrow \omega K^+ K^-$	(5.9	± 2.2	) $\times 10^{-5}$		–
$K^*(892)^0 K^-\pi^+\pi^0$ + c.c.	(8.6	± 2.2	) $\times 10^{-4}$		–
$K^*(892)^+ K^-\pi^+\pi^-$ + c.c.	(9.6	± 2.8	) $\times 10^{-4}$		–
$K^*(892)^+ K^-\rho^0$ + c.c.	(7.3	± 2.6	) $\times 10^{-4}$		–
$K^*(892)^0 K^-\rho^+$ + c.c.	(6.1	± 1.8	) $\times 10^{-4}$		–
$\eta K^+ K^-$, no $\eta\phi$	(3.1	± 0.4	) $\times 10^{-5}$		1664
$\omega K^+ K^-$	(1.62	± 0.11	) $\times 10^{-4}$	S=1.1	1614
$\omega K^*(892)^+ K^-$ + c.c.	(2.07	± 0.26	) $\times 10^{-4}$		1482
$\omega K_2^*(1430)^+ K^-$ + c.c.	(6.1	± 1.2	) $\times 10^{-5}$		1253
$\omega\overline{K}^*(892)^0 K^0$	(1.68	± 0.30	) $\times 10^{-4}$		1481
$\omega\overline{K}_2^*(1430)^0 K^0$	(5.8	± 2.2	) $\times 10^{-5}$		1251
$\omega X(1440) \rightarrow \omega K_S^0 K^-\pi^+$ + c.c.	(1.6	± 0.4	) $\times 10^{-5}$		–
$\omega X(1440) \rightarrow \omega K^+ K^-\pi^0$	(1.09	± 0.26	) $\times 10^{-5}$		–
$\omega f_1(1285) \rightarrow \omega K_S^0 K^-\pi^+$ + c.c.	(3.0	± 1.0	) $\times 10^{-6}$		–
$\omega f_1(1285) \rightarrow \omega K^+ K^-\pi^0$	(1.2	± 0.7	) $\times 10^{-6}$		–
$3(\pi^+\pi^-)$	(3.5	± 2.0	) $\times 10^{-4}$	S=2.8	1774
$p\overline{p}\pi^+\pi^-\pi^0$	(7.3	± 0.7	) $\times 10^{-4}$		1435
K^+K^-	(7.5	± 0.5	) $\times 10^{-5}$		1776
$K_S^0 K_L^0$	(5.34	± 0.33	) $\times 10^{-5}$		1775
$\pi^+\pi^-\pi^0$	(2.01	± 0.17	) $\times 10^{-4}$	S=1.7	1830
$\rho(2150)\pi \rightarrow \pi^+\pi^-\pi^0$	(1.9	$^{+1.2}_{-0.4}$	) $\times 10^{-4}$		–
$\rho(770)\pi \rightarrow \pi^+\pi^-\pi^0$	(3.2	± 1.2	) $\times 10^{-5}$	S=1.8	–
$\pi^+\pi^-$	(7.8	± 2.6	) $\times 10^{-6}$		1838
$K_1(1400)^\pm K^\mp$	$<$ 3.1		$\times 10^{-4}$	CL=90%	1532
$K_2^*(1430)^\pm K^\mp$	(7.1	$^{+1.3}_{-0.9}$	) $\times 10^{-5}$		–
$K^+K^-\pi^0$	(4.07	± 0.31	) $\times 10^{-5}$		1754
$K_S^0 K_L^0 \pi^0$	$<$ 3.0		$\times 10^{-4}$	CL=90%	1753
$K_S^0 K_L^0 \eta$	(1.3	± 0.5	) $\times 10^{-3}$		1661
$K^+K^*(892)^-$ + c.c.	(2.9	± 0.4	) $\times 10^{-5}$	S=1.2	1698
$K^*(892)^0\overline{K}^0$ + c.c.	(1.09	± 0.20	) $\times 10^{-4}$		1697

$\phi \pi^+ \pi^-$	$(1.18 \pm 0.26) \times 10^{-4}$	S=1.5	1690
$\quad \phi f_0(980) \to \pi^+ \pi^-$	$(7.5 \pm 3.3) \times 10^{-5}$	S=1.6	–
$2(K^+ K^-)$	$(6.3 \pm 1.3) \times 10^{-5}$		1499
$\phi K^+ K^-$	$(7.0 \pm 1.6) \times 10^{-5}$		1546
$2(K^+ K^-)\pi^0$	$(1.10 \pm 0.28) \times 10^{-4}$		1440
$\phi \eta$	$(3.10 \pm 0.31) \times 10^{-5}$		1654
$\phi \eta'$	$(3.1 \pm 1.6) \times 10^{-5}$		1555
$\omega \eta'$	$(3.2 {}^{+2.5}_{-2.1}) \times 10^{-5}$		1623
$\omega \pi^0$	$(2.1 \pm 0.6) \times 10^{-5}$		1757
$\rho \eta'$	$(1.9 {}^{+1.7}_{-1.2}) \times 10^{-5}$		1625
$\rho \eta$	$(2.2 \pm 0.6) \times 10^{-5}$	S=1.1	1717
$\omega \eta$	$< 1.1 \times 10^{-5}$	CL=90%	1715
$\phi \pi^0$	$< 4 \times 10^{-7}$	CL=90%	1699
$\eta_c \pi^+ \pi^- \pi^0$	$< 1.0 \times 10^{-3}$	CL=90%	512
$p \overline{p} K^+ K^-$	$(2.7 \pm 0.7) \times 10^{-5}$		1118
$\overline{\Lambda} n K^0_S$ + c.c.	$(8.1 \pm 1.8) \times 10^{-5}$		1324
$\phi f'_2(1525)$	$(4.4 \pm 1.6) \times 10^{-5}$		1321
$\Theta(1540)\overline{\Theta}(1540) \to K^0_S p K^- \overline{n}$ + c.c.	$< 8.8 \times 10^{-6}$	CL=90%	–
$\Theta(1540) K^- \overline{n} \to K^0_S p K^- \overline{n}$	$< 1.0 \times 10^{-5}$	CL=90%	–
$\Theta(1540) K^0_S \overline{p} \to K^0_S \overline{p} K^+ n$	$< 7.0 \times 10^{-6}$	CL=90%	–
$\overline{\Theta}(1540) K^+ n \to K^0_S \overline{p} K^+ n$	$< 2.6 \times 10^{-5}$	CL=90%	–
$\overline{\Theta}(1540) K^0_S p \to K^0_S p K^- \overline{n}$	$< 6.0 \times 10^{-6}$	CL=90%	–
$K^0_S K^0_S$	$< 4.6 \times 10^{-6}$		1775
Radiative decays			
$\gamma \chi_{c0}(1P)$	(9.79 ± 0.20) %		261
$\gamma \chi_{c1}(1P)$	(9.75 ± 0.24) %		171
$\gamma \chi_{c2}(1P)$	(9.52 ± 0.20) %		128
$\gamma \eta_c(1S)$	$(3.4 \pm 0.5) \times 10^{-3}$	S=1.3	635
$\gamma \eta_c(2S)$	$(7 \pm 5) \times 10^{-4}$		48
$\gamma \pi^0$	$(1.04 \pm 0.22) \times 10^{-6}$	S=1.4	1841
$\gamma \eta'(958)$	$(1.24 \pm 0.04) \times 10^{-4}$		1719
$\gamma f_2(1270)$	$(2.73 {}^{+0.29}_{-0.25}) \times 10^{-4}$	S=1.8	1622
$\gamma f_0(1370) \to \gamma K \overline{K}$	$(3.1 \pm 1.7) \times 10^{-5}$		1588
$\gamma f_0(1500)$	$(9.2 \pm 1.9) \times 10^{-5}$		1536
$\gamma f'_2(1525)$	$(3.3 \pm 0.8) \times 10^{-5}$		1528
$\quad \gamma f_0(1710) \to \gamma \pi \pi$	$(3.5 \pm 0.6) \times 10^{-5}$		–
$\quad \gamma f_0(1710) \to \gamma K \overline{K}$	$(6.6 \pm 0.7) \times 10^{-5}$		–
$\gamma f_0(2100) \to \gamma \pi \pi$	$(4.8 \pm 1.0) \times 10^{-6}$		1244
$\gamma f_0(2200) \to \gamma K \overline{K}$	$(3.2 \pm 1.0) \times 10^{-6}$		1193
$\gamma f_J(2220) \to \gamma \pi \pi$	$< 5.8 \times 10^{-6}$	CL=90%	1168
$\gamma f_J(2220) \to \gamma K \overline{K}$	$< 9.5 \times 10^{-6}$	CL=90%	1168
$\gamma \gamma$	$< 1.5 \times 10^{-4}$	CL=90%	1843
$\gamma \eta$	$(9.2 \pm 1.8) \times 10^{-7}$		1802
$\gamma \eta \pi^+ \pi^-$	$(8.7 \pm 2.1) \times 10^{-4}$		1791
$\quad \gamma \eta(1405) \to \gamma K \overline{K} \pi$	$< 9 \times 10^{-5}$	CL=90%	1569
$\quad \gamma \eta(1405) \to \eta \pi^+ \pi^-$	$(3.6 \pm 2.5) \times 10^{-5}$		–
$\quad \gamma \eta(1405) \to \gamma f_0(980) \pi^0 \to \gamma \pi^+ \pi^- \pi^0$	$< 5.0 \times 10^{-7}$	CL=90%	–
$\quad \gamma \eta(1475) \to K \overline{K} \pi$	$< 1.4 \times 10^{-4}$	CL=90%	–
$\quad \gamma \eta(1475) \to \eta \pi^+ \pi^-$	$< 8.8 \times 10^{-5}$	CL=90%	–
$\gamma 2(\pi^+ \pi^-)$	$(4.0 \pm 0.6) \times 10^{-4}$		1817

$\gamma K^{*0} K^+ \pi^- +$ c.c.		$(3.7 \pm 0.9) \times 10^{-4}$		1674
$\gamma K^{*0} \overline{K}^{*0}$		$(2.4 \pm 0.7) \times 10^{-4}$		1613
$\gamma K^0_S K^+ \pi^- +$ c.c.		$(2.6 \pm 0.5) \times 10^{-4}$		1753
$\gamma K^+ K^- \pi^+ \pi^-$		$(1.9 \pm 0.5) \times 10^{-4}$		1726
$\gamma p \overline{p}$		$(3.9 \pm 0.5) \times 10^{-5}$	S=2.0	1586
$\gamma f_2(1950) \to \gamma p \overline{p}$		$(1.20 \pm 0.22) \times 10^{-5}$		–
$\gamma f_2(2150) \to \gamma p \overline{p}$		$(7.2 \pm 1.8) \times 10^{-6}$		–
$\gamma X(1835) \to \gamma p \overline{p}$		$(4.6 {}^{+1.8}_{-4.0}) \times 10^{-6}$		–
$\gamma X \to \gamma p \overline{p}$	[vvaa]	$< 2 \times 10^{-6}$	CL=90%	–
$\gamma \pi^+ \pi^- p \overline{p}$		$(2.8 \pm 1.4) \times 10^{-5}$		1491
$\gamma 2(\pi^+ \pi^-) K^+ K^-$		$< 2.2 \times 10^{-4}$	CL=90%	1654
$\gamma 3(\pi^+ \pi^-)$		$< 1.7 \times 10^{-4}$	CL=90%	1774
$\gamma K^+ K^- K^+ K^-$		$< 4 \times 10^{-5}$	CL=90%	1499
$\gamma \gamma J/\psi$		$(3.1 {}^{+1.0}_{-1.2}) \times 10^{-4}$		542
$e^+ e^- \chi_{c0}(1P)$		$(1.06 \pm 0.24) \times 10^{-3}$		261
$e^+ e^- \chi_{c1}(1P)$		$(8.5 \pm 0.6) \times 10^{-4}$		171
$e^+ e^- \chi_{c2}(1P)$		$(7.0 \pm 0.8) \times 10^{-4}$		128
Weak decays				
$D^0 e^+ e^- +$ c.c.		$< 1.4 \times 10^{-7}$	CL=90%	1371
Other decays				
invisible		< 1.6 %	CL=90%	–

$\psi(3770)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 3773.13 \pm 0.35$ MeV (S = 1.1)
Full width $\Gamma = 27.2 \pm 1.0$ MeV
$\Gamma_{ee} = 0.262 \pm 0.018$ keV (S = 1.4)

In addition to the dominant decay mode to $D\overline{D}$, $\psi(3770)$ was found to decay into the final states containing the J/ψ (BAI 05, ADAM 06). ADAMS 06 and HUANG 06A searched for various decay modes with light hadrons and found a statistically significant signal for the decay to $\phi\eta$ only (ADAMS 06).

$\psi(3770)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$D\overline{D}$	$(93 {}^{+8}_{-9})$ %	S=2.0	286
$D^0 \overline{D}^0$	$(52 {}^{+4}_{-5})$ %	S=2.0	286
$D^+ D^-$	(41 ± 4) %	S=2.0	252
$J/\psi \pi^+ \pi^-$	$(1.93 \pm 0.28) \times 10^{-3}$		560
$J/\psi \pi^0 \pi^0$	$(8.0 \pm 3.0) \times 10^{-4}$		564
$J/\psi \eta$	$(9 \pm 4) \times 10^{-4}$		360
$J/\psi \pi^0$	$< 2.8 \times 10^{-4}$	CL=90%	603
$e^+ e^-$	$(9.6 \pm 0.7) \times 10^{-6}$	S=1.3	1887
Decays to light hadrons			
$b_1(1235)\pi$	$< 1.4 \times 10^{-5}$	CL=90%	1683
$\phi \eta'$	$< 7 \times 10^{-4}$	CL=90%	1607
$\omega \eta'$	$< 4 \times 10^{-4}$	CL=90%	1672
$\rho^0 \eta'$	$< 6 \times 10^{-4}$	CL=90%	1674
$\phi \eta$	$(3.1 \pm 0.7) \times 10^{-4}$		1703
$\omega \eta$	$< 1.4 \times 10^{-5}$	CL=90%	1762
$\rho^0 \eta$	$< 5 \times 10^{-4}$	CL=90%	1764
$\phi \pi^0$	$< 3 \times 10^{-5}$	CL=90%	1746

$\omega\pi^0$	$<$ 6	$\times 10^{-4}$	CL=90%	1803
$\pi^+\pi^-\pi^0$	$<$ 5	$\times 10^{-6}$	CL=90%	1874
$\rho\pi$	$<$ 5	$\times 10^{-6}$	CL=90%	1804
$K^*(892)^+K^-$ + c.c.	$<$ 1.4	$\times 10^{-5}$	CL=90%	1745
$K^*(892)^0\overline{K}^0$ + c.c.	$<$ 1.2	$\times 10^{-3}$	CL=90%	1744
$K^0_S K^0_L$	$<$ 1.2	$\times 10^{-5}$	CL=90%	1820
$2(\pi^+\pi^-)$	$<$ 1.12	$\times 10^{-3}$	CL=90%	1861
$2(\pi^+\pi^-)\pi^0$	$<$ 1.06	$\times 10^{-3}$	CL=90%	1843
$2(\pi^+\pi^-\pi^0)$	$<$ 5.85	%	CL=90%	1821
$\omega\pi^+\pi^-$	$<$ 6.0	$\times 10^{-4}$	CL=90%	1794
$3(\pi^+\pi^-)$	$<$ 9.1	$\times 10^{-3}$	CL=90%	1819
$3(\pi^+\pi^-)\pi^0$	$<$ 1.37	%	CL=90%	1792
$3(\pi^+\pi^-)2\pi^0$	$<$ 11.74	%	CL=90%	1760
$\eta\pi^+\pi^-$	$<$ 1.24	$\times 10^{-3}$	CL=90%	1836
$\pi^+\pi^-2\pi^0$	$<$ 8.9	$\times 10^{-3}$	CL=90%	1862
$\rho^0\pi^+\pi^-$	$<$ 6.9	$\times 10^{-3}$	CL=90%	1796
$\eta 3\pi$	$<$ 1.34	$\times 10^{-3}$	CL=90%	1824
$\eta 2(\pi^+\pi^-)$	$<$ 2.43	%	CL=90%	1804
$\eta\rho^0\pi^+\pi^-$	$<$ 1.45	%	CL=90%	1708
$\eta' 3\pi$	$<$ 2.44	$\times 10^{-3}$	CL=90%	1740
$K^+K^-\pi^+\pi^-$	$<$ 9.0	$\times 10^{-4}$	CL=90%	1772
$\phi\pi^+\pi^-$	$<$ 4.1	$\times 10^{-4}$	CL=90%	1737
$K^+K^-2\pi^0$	$<$ 4.2	$\times 10^{-3}$	CL=90%	1774
$4(\pi^+\pi^-)$	$<$ 1.67	%	CL=90%	1757
$4(\pi^+\pi^-)\pi^0$	$<$ 3.06	%	CL=90%	1720
$\phi f_0(980)$	$<$ 4.5	$\times 10^{-4}$	CL=90%	1597
$K^+K^-\pi^+\pi^-\pi^0$	$<$ 2.36	$\times 10^{-3}$	CL=90%	1741
$K^+K^-\rho^0\pi^0$	$<$ 8	$\times 10^{-4}$	CL=90%	1624
$K^+K^-\rho^+\pi^-$	$<$ 1.46	%	CL=90%	1622
ωK^+K^-	$<$ 3.4	$\times 10^{-4}$	CL=90%	1664
$\phi\pi^+\pi^-\pi^0$	$<$ 3.8	$\times 10^{-3}$	CL=90%	1722
$K^{*0}K^-\pi^+\pi^0$ + c.c.	$<$ 1.62	%	CL=90%	1693
$K^{*+}K^-\pi^+\pi^-$ + c.c.	$<$ 3.23	%	CL=90%	1692
$K^+K^-\pi^+\pi^-2\pi^0$	$<$ 2.67	%	CL=90%	1705
$K^+K^-2(\pi^+\pi^-)$	$<$ 1.03	%	CL=90%	1702
$K^+K^-2(\pi^+\pi^-)\pi^0$	$<$ 3.60	%	CL=90%	1660
ηK^+K^-	$<$ 4.1	$\times 10^{-4}$	CL=90%	1712
$\eta K^+K^-\pi^+\pi^-$	$<$ 1.24	%	CL=90%	1624
$\rho^0K^+K^-$	$<$ 5.0	$\times 10^{-3}$	CL=90%	1665
$2(K^+K^-)$	$<$ 6.0	$\times 10^{-4}$	CL=90%	1552
ϕK^+K^-	$<$ 7.5	$\times 10^{-4}$	CL=90%	1598
$2(K^+K^-)\pi^0$	$<$ 2.9	$\times 10^{-4}$	CL=90%	1493
$2(K^+K^-)\pi^+\pi^-$	$<$ 3.2	$\times 10^{-3}$	CL=90%	1425
$K^0_S K^-\pi^+$	$<$ 3.2	$\times 10^{-3}$	CL=90%	1799
$K^0_S K^-\pi^+\pi^0$	$<$ 1.33	%	CL=90%	1773
$K^0_S K^-\rho^+$	$<$ 6.6	$\times 10^{-3}$	CL=90%	1664
$K^0_S K^-2\pi^+\pi^-$	$<$ 8.7	$\times 10^{-3}$	CL=90%	1739
$K^0_S K^-\pi^+\rho^0$	$<$ 1.6	%	CL=90%	1621
$K^0_S K^-\pi^+\eta$	$<$ 1.3	%	CL=90%	1669
$K^0_S K^-2\pi^+\pi^-\pi^0$	$<$ 4.18	%	CL=90%	1703
$K^0_S K^-2\pi^+\pi^-\eta$	$<$ 4.8	%	CL=90%	1570
$K^0_S K^-\pi^+2(\pi^+\pi^-)$	$<$ 1.22	%	CL=90%	1658
$K^0_S K^-\pi^+2\pi^0$	$<$ 2.65	%	CL=90%	1742
$K^0_S K^-K^+K^-\pi^+$	$<$ 4.9	$\times 10^{-3}$	CL=90%	1490

$K^0_S K^- K^+ K^- \pi^+ \pi^0$	$<$ 3.0	%	CL=90%	1427
$K^0_S K^- K^+ K^- \pi^+ \eta$	$<$ 2.2	%	CL=90%	1214
$K^{*0} K^- \pi^+$ + c.c.	$<$ 9.7	$\times 10^{-3}$	CL=90%	1722
$p\overline{p}\pi^0$	$<$ 4	$\times 10^{-5}$	CL=90%	1595
$p\overline{p}\pi^+\pi^-$	$<$ 5.8	$\times 10^{-4}$	CL=90%	1544
$\Lambda\overline{\Lambda}$	$<$ 1.2	$\times 10^{-4}$	CL=90%	1521
$p\overline{p}\pi^+\pi^-\pi^0$	$<$ 1.85	$\times 10^{-3}$	CL=90%	1490
$\omega p\overline{p}$	$<$ 2.9	$\times 10^{-4}$	CL=90%	1309
$\Lambda\overline{\Lambda}\pi^0$	$<$ 7	$\times 10^{-5}$	CL=90%	1468
$p\overline{p}2(\pi^+\pi^-)$	$<$ 2.6	$\times 10^{-3}$	CL=90%	1425
$\eta p\overline{p}$	$<$ 5.4	$\times 10^{-4}$	CL=90%	1430
$\eta p\overline{p}\pi^+\pi^-$	$<$ 3.3	$\times 10^{-3}$	CL=90%	1284
$\rho^0 p\overline{p}$	$<$ 1.7	$\times 10^{-3}$	CL=90%	1313
$p\overline{p}K^+K^-$	$<$ 3.2	$\times 10^{-4}$	CL=90%	1185
$\eta p\overline{p}K^+K^-$	$<$ 6.9	$\times 10^{-3}$	CL=90%	736
$\pi^0 p\overline{p}K^+K^-$	$<$ 1.2	$\times 10^{-3}$	CL=90%	1093
$\phi p\overline{p}$	$<$ 1.3	$\times 10^{-4}$	CL=90%	1178
$\Lambda\overline{\Lambda}\pi^+\pi^-$	$<$ 2.5	$\times 10^{-4}$	CL=90%	1404
$\Lambda\overline{p}K^+$	$<$ 2.8	$\times 10^{-4}$	CL=90%	1387
$\Lambda\overline{p}K^+\pi^+\pi^-$	$<$ 6.3	$\times 10^{-4}$	CL=90%	1234
$\Lambda\overline{\Lambda}\eta$	$<$ 1.9	$\times 10^{-4}$	CL=90%	1262
$\Sigma^+\overline{\Sigma}^-$	$<$ 1.0	$\times 10^{-4}$	CL=90%	1464
$\Sigma^0\overline{\Sigma}^0$	$<$ 4	$\times 10^{-5}$	CL=90%	1462
$\Xi^+\overline{\Xi}^-$	$<$ 1.5	$\times 10^{-4}$	CL=90%	1346
$\Xi^0\overline{\Xi}^0$	$<$ 1.4	$\times 10^{-4}$	CL=90%	1353
Radiative decays				
$\gamma\chi_{c2}$	$<$ 6.4	$\times 10^{-4}$	CL=90%	211
$\gamma\chi_{c1}$	(2.49±0.23)	$\times 10^{-3}$		253
$\gamma\chi_{c0}$	(6.9 ±0.6)	$\times 10^{-3}$		341
$\gamma\eta_c$	$<$ 7	$\times 10^{-4}$	CL=90%	707
$\gamma\eta_c(2S)$	$<$ 9	$\times 10^{-4}$	CL=90%	133
$\gamma\eta'$	$<$ 1.8	$\times 10^{-4}$	CL=90%	1765
$\gamma\eta$	$<$ 1.5	$\times 10^{-4}$	CL=90%	1847
$\gamma\pi^0$	$<$ 2	$\times 10^{-4}$	CL=90%	1884

$\psi_2(3823)$

$I^G(J^{PC}) = 0^-(2^{--})$
I, J, P need confirmation.

Mass $m = 3822.2 \pm 1.2$ MeV
Full width $\Gamma < 16$ MeV, CL = 90%

$\chi_{c1}(3872)$

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 3871.69 \pm 0.17$ MeV
$m_{\chi_{c1}(3872)} - m_{J/\psi} = 775 \pm 4$ MeV
Full width $\Gamma < 1.2$ MeV, CL = 90%

χ_{c1}(3872) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi^+\pi^- J/\psi(1S)$	$>$ 3.2 %	650
$\omega J/\psi(1S)$	$>$ 2.3 %	†
$D^0\overline{D}^0\pi^0$	$>$40 %	117
$\overline{D}^{*0} D^0$	$>$30 %	3
$\gamma J/\psi$	$>$ 7 $\times 10^{-3}$	697
$\gamma\psi(2S)$	$>$ 4 %	181

See Particle Listings for 3 decay modes that have been seen / not seen.

$Z_c(3900)$

$I^G(J^{PC}) = 1^+(1^{+-})$

Mass $m = 3886.6 \pm 2.4$ MeV (S = 1.6)
Full width $\Gamma = 28.2 \pm 2.6$ MeV

$X(3915)$

$I^G(J^{PC}) = 0^+(0 \text{ or } 2^{++})$

Mass $m = 3918.4 \pm 1.9$ MeV
Full width $\Gamma = 20 \pm 5$ MeV (S = 1.1)

$\chi_{c2}(3930)$

$I^G(J^{PC}) = 0^+(2^{++})$

Mass $m = 3927.2 \pm 2.6$ MeV
Full width $\Gamma = 24 \pm 6$ MeV

$X(4020)$

$I^G(J^{PC}) = 1^+(?^{?-})$

Mass $m = 4024.1 \pm 1.9$ MeV
Full width $\Gamma = 13 \pm 5$ MeV (S = 1.7)

$\psi(4040)$ [xxaa]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 4039 \pm 1$ MeV
Full width $\Gamma = 80 \pm 10$ MeV
$\Gamma_{ee} = 0.86 \pm 0.07$ keV

Due to the complexity of the $c\overline{c}$ threshold region, in this listing, "seen" ("not seen") means that a cross section for the mode in question has been measured at effective $\sqrt{s}$ near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in $\sqrt{s}$ or absence thereof. See mode listing(s) for details and references.

$\psi(4040)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
e^+e^-	$(1.07\pm0.16) \times 10^{-5}$		2019
$J/\psi\pi^+\pi^-$	$< 4 \times 10^{-3}$	90%	794
$J/\psi\pi^0\pi^0$	$< 2 \times 10^{-3}$	90%	797
$J/\psi\eta$	$(5.2 \pm0.7) \times 10^{-3}$		675
$J/\psi\pi^0$	$< 2.8 \times 10^{-4}$	90%	823
$J/\psi\pi^+\pi^-\pi^0$	$< 2 \times 10^{-3}$	90%	746
$\chi_{c1}\gamma$	$< 3.4 \times 10^{-3}$	90%	494
$\chi_{c2}\gamma$	$< 5 \times 10^{-3}$	90%	454
$\chi_{c1}\pi^+\pi^-\pi^0$	< 1.1 %	90%	306
$\chi_{c2}\pi^+\pi^-\pi^0$	< 3.2 %	90%	233
$h_c(1P)\pi^+\pi^-$	$< 3 \times 10^{-3}$	90%	403
$\phi\pi^+\pi^-$	$< 3 \times 10^{-3}$	90%	1880
$\Lambda\overline{\Lambda}\pi^+\pi^-$	$< 2.9 \times 10^{-4}$	90%	1578
$\Lambda\overline{\Lambda}\pi^0$	$< 9 \times 10^{-5}$	90%	1636
$\Lambda\overline{\Lambda}\eta$	$< 3.0 \times 10^{-4}$	90%	1452
$\Sigma^+\overline{\Sigma}^-$	$< 1.3 \times 10^{-4}$	90%	1632
$\Sigma^0\overline{\Sigma}^0$	$< 7 \times 10^{-5}$	90%	1630

$\Xi^+ \overline{\Xi}^-$	< 1.6	$\times 10^{-4}$	90%	1527
$\Xi^0 \overline{\Xi}^0$	< 1.8	$\times 10^{-4}$	90%	1533

See Particle Listings for 13 decay modes that have been seen / not seen.

$\chi_{c1}(4140)$

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 4146.8 \pm 2.4$ MeV (S = 1.1)
Full width $\Gamma = 22^{+8}_{-7}$ MeV (S = 1.3)

$\psi(4160)$ [xxaa]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 4191 \pm 5$ MeV
Full width $\Gamma = 70 \pm 10$ MeV
$\Gamma_{ee} = 0.48 \pm 0.22$ keV

Due to the complexity of the $c\overline{c}$ threshold region, in this listing, "seen" ("not seen") means that a cross section for the mode in question has been measured at effective $\sqrt{s}$ near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in $\sqrt{s}$ or absence thereof. See mode listing(s) for details and references.

ψ(4160) DECAY MODES	Fraction (Γ_i/Γ)		Confidence level	p (MeV/c)
e^+e^-	(6.9 ± 3.3)	$\times 10^{-6}$		2096
$J/\psi\pi^+\pi^-$	< 3	$\times 10^{-3}$	90%	919
$J/\psi\pi^0\pi^0$	< 3	$\times 10^{-3}$	90%	922
$J/\psi K^+K^-$	< 2	$\times 10^{-3}$	90%	407
$J/\psi\eta$	< 8	$\times 10^{-3}$	90%	822
$J/\psi\pi^0$	< 1	$\times 10^{-3}$	90%	944
$J/\psi\eta'$	< 5	$\times 10^{-3}$	90%	457
$J/\psi\pi^+\pi^-\pi^0$	< 1	$\times 10^{-3}$	90%	879
$\psi(2S)\pi^+\pi^-$	< 4	$\times 10^{-3}$	90%	396
$\chi_{c1}\gamma$	< 5	$\times 10^{-3}$	90%	625
$\chi_{c2}\gamma$	< 1.3	%	90%	587
$\chi_{c1}\pi^+\pi^-\pi^0$	< 2	$\times 10^{-3}$	90%	496
$\chi_{c2}\pi^+\pi^-\pi^0$	< 8	$\times 10^{-3}$	90%	445
$h_c(1P)\pi^+\pi^-$	< 5	$\times 10^{-3}$	90%	556
$h_c(1P)\pi^0\pi^0$	< 2	$\times 10^{-3}$	90%	560
$h_c(1P)\eta$	< 2	$\times 10^{-3}$	90%	348
$h_c(1P)\pi^0$	< 4	$\times 10^{-4}$	90%	600
$\phi\pi^+\pi^-$	< 2	$\times 10^{-3}$	90%	1961
$\gamma\chi_{c1}(3872) \to \gamma J/\psi\pi^+\pi^-$	< 6.8	$\times 10^{-5}$	90%	–
$\gamma X(3915) \to \gamma J/\psi\pi^+\pi^-$	< 1.36	$\times 10^{-4}$	90%	–
$\gamma X(3930) \to \gamma J/\psi\pi^+\pi^-$	< 1.18	$\times 10^{-4}$	90%	–
$\gamma X(3940) \to \gamma J/\psi\pi^+\pi^-$	< 1.47	$\times 10^{-4}$	90%	–
$\gamma\chi_{c1}(3872) \to \gamma\gamma J/\psi$	< 1.05	$\times 10^{-4}$	90%	–
$\gamma X(3915) \to \gamma\gamma J/\psi$	< 1.26	$\times 10^{-4}$	90%	–
$\gamma X(3930) \to \gamma\gamma J/\psi$	< 8.8	$\times 10^{-5}$	90%	–
$\gamma X(3940) \to \gamma\gamma J/\psi$	< 1.79	$\times 10^{-4}$	90%	–

See Particle Listings for 15 decay modes that have been seen / not seen.

$\psi(4260)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 4230 \pm 8$ MeV (S = 2.9)
Full width $\Gamma = 55 \pm 19$ MeV (S = 4.4)

$\chi_{c1}(4274)$

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 4274^{+8}_{-6}$ MeV
Full width $\Gamma = 49 \pm 12$ MeV

$\psi(4360)$

$I^G(J^{PC}) = 0^-(1^{--})$
I needs confirmation.

$\psi(4360)$ MASS = 4368 ± 13 MeV (S = 3.7)
$\psi(4360)$ WIDTH = 96 ± 7 MeV

$\psi(4415)$ [xxaa]

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 4421 \pm 4$ MeV
Full width $\Gamma = 62 \pm 20$ MeV
$\Gamma_{ee} = 0.58 \pm 0.07$ keV

Due to the complexity of the $c\overline{c}$ threshold region, in this listing, "seen" ("not seen") means that a cross section for the mode in question has been measured at effective $\sqrt{s}$ near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in $\sqrt{s}$ or absence thereof. See mode listing(s) for details and references.

$\psi(4415)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$D^0 D^- \pi^+$ (excl. $D^*(2007)^0 \overline{D}^0$ +c.c., $D^*(2010)^+ D^-$ +c.c.	$<$ 2.3 %	90%	–
$D \overline{D}^*_2(2460) \rightarrow D^0 D^- \pi^+$ +c.c.	(10 $\pm$4) %		–
$D^0 D^{*-} \pi^+$ +c.c.	$<$ 11 %	90%	926
$J/\psi \eta$	$< 6 \times 10^{-3}$	90%	1022
$\chi_{c1} \gamma$	$< 8 \times 10^{-4}$	90%	817
$\chi_{c2} \gamma$	$< 4 \times 10^{-3}$	90%	780
$e^+ e^-$	$(9.4 \pm 3.2) \times 10^{-6}$		2210

See Particle Listings for 14 decay modes that have been seen / not seen.

$Z_c(4430)$

$I^G(J^{PC}) = 1^+(1^{+-})$
I, G, C need confirmation.

Quantum numbers not established.

Mass $m = 4478^{+15}_{-18}$ MeV
Full width $\Gamma = 181 \pm 31$ MeV

$\psi(4660)$

$I^G(J^{PC}) = 0^-(1^{--})$
I needs confirmation.

$\psi(4660)$ MASS = 4643 ± 9 MeV (S = 1.2)
$\psi(4660)$ WIDTH = 72 ± 11 MeV

$b\overline{b}$ MESONS (including possibly non-$q\overline{q}$ states)

$\eta_b(1S)$

$I^G(J^{PC}) = 0^+(0^{-+})$

Mass $m = 9399.0 \pm 2.3$ MeV (S = 1.6)
Full width $\Gamma = 10^{+5}_{-4}$ MeV

$\eta_b(1S)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\mu^+\mu^-$	$<9 \times 10^{-3}$	90%	4698
$\tau^+\tau^-$	<8 %	90%	4351

See Particle Listings for 4 decay modes that have been seen / not seen.

$\Upsilon(1S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 9460.30 \pm 0.26$ MeV (S = 3.3)
Full width $\Gamma = 54.02 \pm 1.25$ keV
$\Gamma_{ee} = 1.340 \pm 0.018$ keV

$\Upsilon(1S)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\tau^+\tau^-$	(2.60 ±0.10) %		4384
e^+e^-	(2.38 ±0.11) %		4730
$\mu^+\mu^-$	(2.48 ±0.05) %		4729
Hadronic decays			
ggg	(81.7 ±0.7) %		–
γgg	(2.2 ±0.6) %		–
$\eta'(958)$ anything	(2.94 ±0.24) %		–
$J/\psi(1S)$ anything	(5.4 ±0.4) $\times 10^{-4}$	S=1.4	4223
$J/\psi(1S)\eta_c$	$<$ 2.2 $\times 10^{-6}$	CL=90%	3623
$J/\psi(1S)\chi_{c0}$	$<$ 3.4 $\times 10^{-6}$	CL=90%	3429
$J/\psi(1S)\chi_{c1}$	(3.9 ±1.2) $\times 10^{-6}$		3382
$J/\psi(1S)\chi_{c2}$	$<$ 1.4 $\times 10^{-6}$	CL=90%	3359
$J/\psi(1S)\eta_c(2S)$	$<$ 2.2 $\times 10^{-6}$	CL=90%	3317
$J/\psi(1S)X(3940)$	$<$ 5.4 $\times 10^{-6}$	CL=90%	3148
$J/\psi(1S)X(4160)$	$<$ 5.4 $\times 10^{-6}$	CL=90%	3018
$X(4350)$ anything, $X \to J/\psi(1S)\phi$	$<$ 8.1 $\times 10^{-6}$	CL=90%	–
$Z_c(3900)^{\pm}$ anything, $Z_c \to J/\psi(1S)\pi^{\pm}$	$<$ 1.3 $\times 10^{-5}$	CL=90%	–
$Z_c(4200)^{\pm}$ anything, $Z_c \to J/\psi(1S)\pi^{\pm}$	$<$ 6.0 $\times 10^{-5}$	CL=90%	–
$Z_c(4430)^{\pm}$ anything, $Z_c \to J/\psi(1S)\pi^{\pm}$	$<$ 4.9 $\times 10^{-5}$	CL=90%	–
$X^{\pm}_{cs}$ anything, $X \to J/\psi K^{\pm}$	$<$ 5.7 $\times 10^{-6}$	CL=90%	–
$\chi_{c1}(3872)$ anything, $\chi_{c1} \to J/\psi(1S)\pi^+\pi^-$	$<$ 9.5 $\times 10^{-6}$	CL=90%	–
$\psi(4260)$ anything, $\psi \to J/\psi(1S)\pi^+\pi^-$	$<$ 3.8 $\times 10^{-5}$	CL=90%	–
$\psi(4260)$ anything, $\psi \to J/\psi(1S)K^+K^-$	$<$ 7.5 $\times 10^{-6}$	CL=90%	–

$\chi_{c1}(4140)$ anything, $\chi_{c1} \to J/\psi(1S)\phi$		$< 5.2 \times 10^{-6}$	CL=90%	–
χ_{c0} anything		$< 4 \times 10^{-3}$	CL=90%	–
χ_{c1} anything		$(1.90 \pm 0.35) \times 10^{-4}$		–
$\chi_{c1}(1P) X_{tetra}$		$< 3.78 \times 10^{-5}$	CL=90%	–
χ_{c2} anything		$(2.8 \pm 0.8) \times 10^{-4}$		–
$\psi(2S)$ anything		$(1.23 \pm 0.20) \times 10^{-4}$		–
$\psi(2S)\eta_c$		$< 3.6 \times 10^{-6}$	CL=90%	3345
$\psi(2S)\chi_{c0}$		$< 6.5 \times 10^{-6}$	CL=90%	3124
$\psi(2S)\chi_{c1}$		$< 4.5 \times 10^{-6}$	CL=90%	3070
$\psi(2S)\chi_{c2}$		$< 2.1 \times 10^{-6}$	CL=90%	3043
$\psi(2S)\eta_c(2S)$		$< 3.2 \times 10^{-6}$	CL=90%	2994
$\psi(2S) X(3940)$		$< 2.9 \times 10^{-6}$	CL=90%	2797
$\psi(2S) X(4160)$		$< 2.9 \times 10^{-6}$	CL=90%	2642
$\psi(4260)$ anything, $\psi \to \psi(2S)\pi^+\pi^-$		$< 7.9 \times 10^{-5}$	CL=90%	–
$\psi(4360)$ anything, $\psi \to \psi(2S)\pi^+\pi^-$		$< 5.2 \times 10^{-5}$	CL=90%	–
$\psi(4660)$ anything, $\psi \to \psi(2S)\pi^+\pi^-$		$< 2.2 \times 10^{-5}$	CL=90%	–
$X(4050)^\pm$ anything, $X \to \psi(2S)\pi^\pm$		$< 8.8 \times 10^{-5}$	CL=90%	–
$Z_c(4430)^\pm$ anything, $Z_c \to \psi(2S)\pi^\pm$		$< 6.7 \times 10^{-5}$	CL=90%	–
$\rho\pi$		$< 3.68 \times 10^{-6}$	CL=90%	4697
$\omega\pi^0$		$< 3.90 \times 10^{-6}$	CL=90%	4697
$\pi^+\pi^-$		$< 5 \times 10^{-4}$	CL=90%	4728
K^+K^-		$< 5 \times 10^{-4}$	CL=90%	4704
$p\overline{p}$		$< 5 \times 10^{-4}$	CL=90%	4636
$\pi^+\pi^-\pi^0$		$(2.1 \pm 0.8) \times 10^{-6}$		4725
ϕK^+K^-		$(2.4 \pm 0.5) \times 10^{-6}$		4622
$\omega\pi^+\pi^-$		$(4.5 \pm 1.0) \times 10^{-6}$		4694
$K^*(892)^0 K^-\pi^+ +$ c.c.		$(4.4 \pm 0.8) \times 10^{-6}$		4667
$\phi f_2'(1525)$		$< 1.63 \times 10^{-6}$	CL=90%	4549
$\omega f_2(1270)$		$< 1.79 \times 10^{-6}$	CL=90%	4611
$\rho(770) a_2(1320)$		$< 2.24 \times 10^{-6}$	CL=90%	4605
$K^*(892)^0 \overline{K}_2^*(1430)^0 +$ c.c.		$(3.0 \pm 0.8) \times 10^{-6}$		4579
$K_1(1270)^\pm K^\mp$		$< 2.41 \times 10^{-6}$	CL=90%	4631
$K_1(1400)^\pm K^\mp$		$(1.0 \pm 0.4) \times 10^{-6}$		4613
$b_1(1235)^\pm \pi^\mp$		$< 1.25 \times 10^{-6}$	CL=90%	4649
$\pi^+\pi^-\pi^0\pi^0$		$(1.28 \pm 0.30) \times 10^{-5}$		4720
$K_S^0 K^+\pi^- +$ c.c.		$(1.6 \pm 0.4) \times 10^{-6}$		4696
$K^*(892)^0 \overline{K}^0 +$ c.c.		$(2.9 \pm 0.9) \times 10^{-6}$		4675
$K^*(892)^- K^+ +$ c.c.		$< 1.11 \times 10^{-6}$	CL=90%	4675
$f_1(1285)$ anything		$(4.6 \pm 3.1) \times 10^{-3}$		–
$D^*(2010)^\pm$ anything		(2.52 ± 0.20) %		–
$f_1(1285) X_{tetra}$		$< 6.24 \times 10^{-5}$	CL=90%	–
^2H anything		$(2.85 \pm 0.25) \times 10^{-5}$		–
Sum of 100 exclusive modes		(1.200 ± 0.017) %		–
Radiative decays				
$\gamma\pi^+\pi^-$		$(6.3 \pm 1.8) \times 10^{-5}$		4728
$\gamma\pi^0\pi^0$		$(1.7 \pm 0.7) \times 10^{-5}$		4728
$\gamma\pi^0\eta$		$< 2.4 \times 10^{-6}$	CL=90%	4713
γK^+K^-	[yyaa]	$(1.14 \pm 0.13) \times 10^{-5}$		4704

$\gamma p \overline{p}$	[zzaa]	<	6		$\times 10^{-6}$	CL=90%	4636
$\gamma 2h^+ 2h^-$			(7.0 | ± 1.5)	$\times 10^{-4}$		4720
$\gamma 3h^+ 3h^-$			(5.4 | ± 2.0)	$\times 10^{-4}$		4703
$\gamma 4h^+ 4h^-$			(7.4 | ± 3.5)	$\times 10^{-4}$		4679
$\gamma \pi^+ \pi^- K^+ K^-$			(2.9 | ± 0.9)	$\times 10^{-4}$		4686
$\gamma 2\pi^+ 2\pi^-$			(2.5 | ± 0.9)	$\times 10^{-4}$		4720
$\gamma 3\pi^+ 3\pi^-$			(2.5 | ± 1.2)	$\times 10^{-4}$		4703
$\gamma 2\pi^+ 2\pi^- K^+ K^-$			(2.4 | ± 1.2)	$\times 10^{-4}$		4658
$\gamma \pi^+ \pi^- p \overline{p}$			(1.5 | ± 0.6)	$\times 10^{-4}$		4604
$\gamma 2\pi^+ 2\pi^- p \overline{p}$			(4 | ± 6)	$\times 10^{-5}$		4563
$\gamma 2K^+ 2K^-$			(2.0 | ± 2.0)	$\times 10^{-5}$		4601
$\gamma \eta'(958)$		<	1.9		$\times 10^{-6}$	CL=90%	4682
$\gamma \eta$		<	1.0		$\times 10^{-6}$	CL=90%	4714
$\gamma f_0(980)$		<	3		$\times 10^{-5}$	CL=90%	4678
$\gamma f'_2(1525)$			(3.8 | ± 0.9)	$\times 10^{-5}$		4607
$\gamma f_2(1270)$			(1.01 | ± 0.09)	$\times 10^{-4}$		4644
$\gamma \eta(1405)$		<	8.2		$\times 10^{-5}$	CL=90%	4625
$\gamma f_0(1500)$		<	1.5		$\times 10^{-5}$	CL=90%	4611
$\gamma f_0(1710)$		<	2.6		$\times 10^{-4}$	CL=90%	4573
$\gamma f_0(1710) \rightarrow \gamma K^+ K^-$		<	7		$\times 10^{-6}$	CL=90%	–
$\gamma f_0(1710) \rightarrow \gamma \pi^0 \pi^0$		<	1.4		$\times 10^{-6}$	CL=90%	–
$\gamma f_0(1710) \rightarrow \gamma \eta \eta$		<	1.8		$\times 10^{-6}$	CL=90%	–
$\gamma f_4(2050)$		<	5.3		$\times 10^{-5}$	CL=90%	4515
$\gamma f_0(2200) \rightarrow \gamma K^+ K^-$		<	2		$\times 10^{-4}$	CL=90%	4475
$\gamma f_J(2220) \rightarrow \gamma K^+ K^-$		<	8		$\times 10^{-7}$	CL=90%	4469
$\gamma f_J(2220) \rightarrow \gamma \pi^+ \pi^-$		<	6		$\times 10^{-7}$	CL=90%	–
$\gamma f_J(2220) \rightarrow \gamma p \overline{p}$		<	1.1		$\times 10^{-6}$	CL=90%	–
$\gamma \eta(2225) \rightarrow \gamma \phi \phi$		<	3		$\times 10^{-3}$	CL=90%	4469
$\gamma \eta_c(1S)$		<	5.7		$\times 10^{-5}$	CL=90%	4260
$\gamma \chi_{c0}$		<	6.5		$\times 10^{-4}$	CL=90%	4114
$\gamma \chi_{c1}$		<	2.3		$\times 10^{-5}$	CL=90%	4079
$\gamma \chi_{c2}$		<	7.6		$\times 10^{-6}$	CL=90%	4062
$\gamma \chi_{c1}(3872) \rightarrow \pi^+ \pi^- J/\psi$		<	1.6		$\times 10^{-6}$	CL=90%	–
$\gamma \chi_{c1}(3872) \rightarrow \pi^+ \pi^- \pi^0 J/\psi$		<	2.8		$\times 10^{-6}$	CL=90%	–
$\gamma X(3915) \rightarrow \omega J/\psi$		<	3.0		$\times 10^{-6}$	CL=90%	–
$\gamma \chi_{c1}(4140) \rightarrow \phi J/\psi$		<	2.2		$\times 10^{-6}$	CL=90%	–
γX	[aabb]	<	4.5		$\times 10^{-6}$	CL=90%	–
$\gamma X \overline{X} (m_X < 3.1$ GeV)	[bbbb]	<	1		$\times 10^{-3}$	CL=90%	–
$\gamma X \overline{X} (m_X < 4.5$ GeV)	[ccbb]	<	2.4		$\times 10^{-4}$	CL=90%	–
$\gamma X \rightarrow \gamma + \geq 4$ prongs	[ddbb]	<	1.78		$\times 10^{-4}$	CL=95%	–
$\gamma a_1^0 \rightarrow \gamma \mu^+ \mu^-$	[eebb]	<	9		$\times 10^{-6}$	CL=90%	–
$\gamma a_1^0 \rightarrow \gamma \tau^+ \tau^-$	[yyaa]	<	1.30		$\times 10^{-4}$	CL=90%	–
$\gamma a_1^0 \rightarrow \gamma g g$	[ffbb]	<	1		%	CL=90%	–
$\gamma a_1^0 \rightarrow \gamma s \overline{s}$	[ffbb]	<	1		$\times 10^{-3}$	CL=90%	–

Lepton Family number (*LF*) violating modes

$\mu^\pm \tau^\mp$	*LF*	<	6.0	$\times 10^{-6}$	CL=95%	4563

Other decays

invisible		<	3.0	$\times 10^{-4}$	CL=90%	–

$\chi_{b0}(1P)$ [ggbb]

$I^G(J^{PC}) = 0^+(0^{++})$
J needs confirmation.

Mass $m = 9859.44 \pm 0.42 \pm 0.31$ MeV

$\chi_{b0}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\gamma\,\Upsilon(1S)$	$(1.94 \pm 0.27)\,\%$		391
$D^0 X$	$< 10.4\,\%$	90%	–
$\pi^+\pi^- K^+ K^- \pi^0$	$< 1.6 \times 10^{-4}$	90%	4875
$2\pi^+\pi^- K^- K^0_S$	$< 5 \times 10^{-5}$	90%	4875
$2\pi^+\pi^- K^- K^0_S 2\pi^0$	$< 5 \times 10^{-4}$	90%	4846
$2\pi^+ 2\pi^- 2\pi^0$	$< 2.1 \times 10^{-4}$	90%	4905
$2\pi^+ 2\pi^- K^+ K^-$	$(1.1 \pm 0.6) \times 10^{-4}$		4861
$2\pi^+ 2\pi^- K^+ K^- \pi^0$	$< 2.7 \times 10^{-4}$	90%	4846
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$< 5 \times 10^{-4}$	90%	4828
$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	$< 1.6 \times 10^{-4}$	90%	4827
$3\pi^+ 3\pi^-$	$< 8 \times 10^{-5}$	90%	4904
$3\pi^+ 3\pi^- 2\pi^0$	$< 6 \times 10^{-4}$	90%	4881
$3\pi^+ 3\pi^- K^+ K^-$	$(2.4 \pm 1.2) \times 10^{-4}$		4827
$3\pi^+ 3\pi^- K^+ K^- \pi^0$	$< 1.0 \times 10^{-3}$	90%	4808
$4\pi^+ 4\pi^-$	$< 8 \times 10^{-5}$	90%	4880
$4\pi^+ 4\pi^- 2\pi^0$	$< 2.1 \times 10^{-3}$	90%	4850
$J/\psi J/\psi$	$< 7 \times 10^{-5}$	90%	3836
$J/\psi \psi(2S)$	$< 1.2 \times 10^{-4}$	90%	3571
$\psi(2S)\psi(2S)$	$< 3.1 \times 10^{-5}$	90%	3273
$J/\psi(1S)$ anything	$< 2.3 \times 10^{-3}$	90%	–

$\chi_{b1}(1P)$ [ggbb]

$I^G(J^{PC}) = 0^+(1^{++})$
J needs confirmation.

Mass $m = 9892.78 \pm 0.26 \pm 0.31$ MeV

$\chi_{b1}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\gamma\,\Upsilon(1S)$	$(35.0 \pm 2.1)\,\%$		423
$D^0 X$	$(12.6 \pm 2.2)\,\%$		–
$\pi^+\pi^- K^+ K^- \pi^0$	$(2.0 \pm 0.6) \times 10^{-4}$		4892
$2\pi^+\pi^- K^- K^0_S$	$(1.3 \pm 0.5) \times 10^{-4}$		4892
$2\pi^+\pi^- K^- K^0_S 2\pi^0$	$< 6 \times 10^{-4}$	90%	4863
$2\pi^+ 2\pi^- 2\pi^0$	$(8.0 \pm 2.5) \times 10^{-4}$		4921
$2\pi^+ 2\pi^- K^+ K^-$	$(1.5 \pm 0.5) \times 10^{-4}$		4878
$2\pi^+ 2\pi^- K^+ K^- \pi^0$	$(3.5 \pm 1.2) \times 10^{-4}$		4863
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$(8.6 \pm 3.2) \times 10^{-4}$		4845
$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	$(9.3 \pm 3.3) \times 10^{-4}$		4844
$3\pi^+ 3\pi^-$	$(1.9 \pm 0.6) \times 10^{-4}$		4921
$3\pi^+ 3\pi^- 2\pi^0$	$(1.7 \pm 0.5) \times 10^{-3}$		4898
$3\pi^+ 3\pi^- K^+ K^-$	$(2.6 \pm 0.8) \times 10^{-4}$		4844
$3\pi^+ 3\pi^- K^+ K^- \pi^0$	$(7.5 \pm 2.6) \times 10^{-4}$		4825
$4\pi^+ 4\pi^-$	$(2.6 \pm 0.9) \times 10^{-4}$		4897
$4\pi^+ 4\pi^- 2\pi^0$	$(1.4 \pm 0.6) \times 10^{-3}$		4867
ω anything	$(4.9 \pm 1.4)\,\%$		–
ωX_{tetra}	$< 4.44 \times 10^{-4}$	90%	–
$J/\psi J/\psi$	$< 2.7 \times 10^{-5}$	90%	3857

$J/\psi\psi(2S)$	$< 1.7 \times 10^{-5}$		90%	3594
$\psi(2S)\psi(2S)$	$< 6 \times 10^{-5}$		90%	3298
$J/\psi(1S)$anything	$< 1.1 \times 10^{-3}$		90%	–
$J/\psi(1S)X_{tetra}$	$< 2.27 \times 10^{-4}$		90%	–

$h_b(1P)$

$I^G(J^{PC}) = ?^?(1^{+-})$

Mass $m = 9899.3 \pm 0.8$ MeV

$h_b(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\eta_b(1S)\gamma$	(52^{+6}_{-5}) %	488

$\chi_{b2}(1P)$ [ggbb]

$I^G(J^{PC}) = 0^+(2^{++})$
J needs confirmation.

Mass $m = 9912.21 \pm 0.26 \pm 0.31$ MeV

$\chi_{b2}(1P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\gamma\,\Upsilon(1S)$	(18.8 ± 1.1) %		442
$D^0 X$	< 7.9 %	90%	–
$\pi^+\pi^- K^+ K^- \pi^0$	$(8 \pm 5) \times 10^{-5}$		4902
$2\pi^+\pi^- K^- K^0_S$	$< 1.0 \times 10^{-4}$	90%	4901
$2\pi^+\pi^- K^- K^0_S 2\pi^0$	$(5.3 \pm 2.4) \times 10^{-4}$		4873
$2\pi^+ 2\pi^- 2\pi^0$	$(3.5 \pm 1.4) \times 10^{-4}$		4931
$2\pi^+ 2\pi^- K^+ K^-$	$(1.1 \pm 0.4) \times 10^{-4}$		4888
$2\pi^+ 2\pi^- K^+ K^- \pi^0$	$(2.1 \pm 0.9) \times 10^{-4}$		4872
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$(3.9 \pm 1.8) \times 10^{-4}$		4855
$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	$< 5 \times 10^{-4}$	90%	4854
$3\pi^+ 3\pi^-$	$(7.0 \pm 3.1) \times 10^{-5}$		4931
$3\pi^+ 3\pi^- 2\pi^0$	$(1.0 \pm 0.4) \times 10^{-3}$		4908
$3\pi^+ 3\pi^- K^+ K^-$	$< 8 \times 10^{-5}$	90%	4854
$3\pi^+ 3\pi^- K^+ K^- \pi^0$	$(3.6 \pm 1.5) \times 10^{-4}$		4835
$4\pi^+ 4\pi^-$	$(8 \pm 4) \times 10^{-5}$		4907
$4\pi^+ 4\pi^- 2\pi^0$	$(1.8 \pm 0.7) \times 10^{-3}$		4877
$J/\psi J/\psi$	$< 4 \times 10^{-5}$	90%	3869
$J/\psi\psi(2S)$	$< 5 \times 10^{-5}$	90%	3608
$\psi(2S)\psi(2S)$	$< 1.6 \times 10^{-5}$	90%	3313
$J/\psi(1S)$anything	$(1.5 \pm 0.4) \times 10^{-3}$		–

$\Upsilon(2S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 10023.26 \pm 0.31$ MeV
$m_{\Upsilon(3S)} - m_{\Upsilon(2S)} = 331.50 \pm 0.13$ MeV
Full width $\Gamma = 31.98 \pm 2.63$ keV
$\Gamma_{ee} = 0.612 \pm 0.011$ keV

$\Upsilon(2S)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\Upsilon(1S)\pi^+\pi^-$	(17.85 ± 0.26) %		475
$\Upsilon(1S)\pi^0\pi^0$	(8.6 ± 0.4) %		480
$\tau^+\tau^-$	(2.00 ± 0.21) %		4686
$\mu^+\mu^-$	(1.93 ± 0.17) %	S=2.2	5011

$e^+ e^-$	(1.91 ± 0.16) %		5012
$\Upsilon(1S)\pi^0$	$< 4 \times 10^{-5}$	CL=90%	531
$\Upsilon(1S)\eta$	$(2.9 \pm 0.4) \times 10^{-4}$	S=2.0	126
$J/\psi(1S)$ anything	$< 6 \times 10^{-3}$	CL=90%	4533
$J/\psi(1S)\eta_c$	$< 5.4 \times 10^{-6}$	CL=90%	3984
$J/\psi(1S)\chi_{c0}$	$< 3.4 \times 10^{-6}$	CL=90%	3808
$J/\psi(1S)\chi_{c1}$	$< 1.2 \times 10^{-6}$	CL=90%	3765
$J/\psi(1S)\chi_{c2}$	$< 2.0 \times 10^{-6}$	CL=90%	3744
$J/\psi(1S)\eta_c(2S)$	$< 2.5 \times 10^{-6}$	CL=90%	3706
$J/\psi(1S)X(3940)$	$< 2.0 \times 10^{-6}$	CL=90%	3555
$J/\psi(1S)X(4160)$	$< 2.0 \times 10^{-6}$	CL=90%	3440
χ_{c1} anything	$(2.2 \pm 0.5) \times 10^{-4}$		–
$\chi_{c1}(1P)^0 X_{tetra}$	$< 3.67 \times 10^{-5}$	CL=90%	–
χ_{c2} anything	$(2.3 \pm 0.8) \times 10^{-4}$		–
$\psi(2S)\eta_c$	$< 5.1 \times 10^{-6}$	CL=90%	3732
$\psi(2S)\chi_{c0}$	$< 4.7 \times 10^{-6}$	CL=90%	3536
$\psi(2S)\chi_{c1}$	$< 2.5 \times 10^{-6}$	CL=90%	3488
$\psi(2S)\chi_{c2}$	$< 1.9 \times 10^{-6}$	CL=90%	3464
$\psi(2S)\eta_c(2S)$	$< 3.3 \times 10^{-6}$	CL=90%	3422
$\psi(2S)X(3940)$	$< 3.9 \times 10^{-6}$	CL=90%	3250
$\psi(2S)X(4160)$	$< 3.9 \times 10^{-6}$	CL=90%	3118
$\overline{^2H}$ anything	$(2.78^{+0.30}_{-0.26}) \times 10^{-5}$	S=1.2	–
hadrons	(94 ± 11) %		–
ggg	(58.8 ± 1.2) %		–
γgg	(1.87 ± 0.28) %		–
$\phi K^+ K^-$	$(1.6 \pm 0.4) \times 10^{-6}$		4910
$\omega\pi^+\pi^-$	$< 2.58 \times 10^{-6}$	CL=90%	4977
$K^*(892)^0 K^-\pi^+ +$ c.c.	$(2.3 \pm 0.7) \times 10^{-6}$		4952
$\phi f_2'(1525)$	$< 1.33 \times 10^{-6}$	CL=90%	4841
$\omega f_2(1270)$	$< 5.7 \times 10^{-7}$	CL=90%	4899
$\rho(770) a_2(1320)$	$< 8.8 \times 10^{-7}$	CL=90%	4894
$K^*(892)^0 \overline{K}{}_2^*(1430)^0 +$ c.c.	$(1.5 \pm 0.6) \times 10^{-6}$		4869
$K_1(1270)^{\pm} K^{\mp}$	$< 3.22 \times 10^{-6}$	CL=90%	4918
$K_1(1400)^{\pm} K^{\mp}$	$< 8.3 \times 10^{-7}$	CL=90%	4901
$b_1(1235)^{\pm}\pi^{\mp}$	$< 4.0 \times 10^{-7}$	CL=90%	4935
$\rho\pi$	$< 1.16 \times 10^{-6}$	CL=90%	4981
$\pi^+\pi^-\pi^0$	$< 8.0 \times 10^{-7}$	CL=90%	5007
$\omega\pi^0$	$< 1.63 \times 10^{-6}$	CL=90%	4980
$\pi^+\pi^-\pi^0\pi^0$	$(1.30 \pm 0.28) \times 10^{-5}$		5002
$K_S^0 K^+\pi^- +$ c.c.	$(1.14 \pm 0.33) \times 10^{-6}$		4979
$K^*(892)^0 \overline{K}{}^0 +$ c.c.	$< 4.22 \times 10^{-6}$	CL=90%	4959
$K^*(892)^- K^+ +$ c.c.	$< 1.45 \times 10^{-6}$	CL=90%	4960
$f_1(1285)$ anything	$(2.2 \pm 1.6) \times 10^{-3}$		–
$f_1(1285) X_{tetra}$	$< 6.47 \times 10^{-5}$	CL=90%	–
Sum of 100 exclusive modes	$(2.90 \pm 0.30) \times 10^{-3}$		–

Radiative decays

$\gamma\chi_{b1}(1P)$	(6.9 ± 0.4) %		130
$\gamma\chi_{b2}(1P)$	(7.15 ± 0.35) %		110
$\gamma\chi_{b0}(1P)$	(3.8 ± 0.4) %		162
$\gamma f_0(1710)$	$< 5.9 \times 10^{-4}$	CL=90%	4864
$\gamma f_2'(1525)$	$< 5.3 \times 10^{-4}$	CL=90%	4896
$\gamma f_2(1270)$	$< 2.41 \times 10^{-4}$	CL=90%	4930
$\gamma\eta_c(1S)$	$< 2.7 \times 10^{-5}$	CL=90%	4567

$\gamma\chi_{c0}$		$<$ 1.0	$\times 10^{-4}$	CL=90%	4430
$\gamma\chi_{c1}$		$<$ 3.6	$\times 10^{-6}$	CL=90%	4397
$\gamma\chi_{c2}$		$<$ 1.5	$\times 10^{-5}$	CL=90%	4381
$\gamma\chi_{c1}(3872) \to \pi^+\pi^- J/\psi$		$<$ 8	$\times 10^{-7}$	CL=90%	–
$\gamma\chi_{c1}(3872) \to \pi^+\pi^-\pi^0 J/\psi$		$<$ 2.4	$\times 10^{-6}$	CL=90%	–
$\gamma X(3915) \to \omega J/\psi$		$<$ 2.8	$\times 10^{-6}$	CL=90%	–
$\gamma\chi_{c1}(4140) \to \phi J/\psi$		$<$ 1.2	$\times 10^{-6}$	CL=90%	–
$\gamma X(4350) \to \phi J/\psi$		$<$ 1.3	$\times 10^{-6}$	CL=90%	–
$\gamma\eta_b(1S)$		(3.9 $\pm$ 1.5)	$\times 10^{-4}$		605
$\gamma\eta_b(1S) \to \gamma$Sum of 26 exclusive modes		$<$ 3.7	$\times 10^{-6}$	CL=90%	–
$\gamma X_{b\overline{b}} \to \gamma$Sum of 26 exclusive modes		$<$ 4.9	$\times 10^{-6}$	CL=90%	–
$\gamma X \to \gamma + \geq 4$ prongs	[hhbb]	$<$ 1.95	$\times 10^{-4}$	CL=95%	–
$\gamma A^0 \to \gamma$hadrons		$<$ 8	$\times 10^{-5}$	CL=90%	–
$\gamma a_1^0 \to \gamma\mu^+\mu^-$		$<$ 8.3	$\times 10^{-6}$	CL=90%	–
Lepton Family number (*LF*) violating modes					
$e^\pm\tau^\mp$	*LF*	$<$ 3.2	$\times 10^{-6}$	CL=90%	4854
$\mu^\pm\tau^\mp$	*LF*	$<$ 3.3	$\times 10^{-6}$	CL=90%	4854

$\Upsilon_2(1D)$

$I^G(J^{PC}) = 0^-(2^{--})$

Mass $m = 10163.7 \pm 1.4$ MeV (S = 1.7)

$\Upsilon_2(1D)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi^+\pi^-\Upsilon(1S)$	$(6.6\pm1.6) \times 10^{-3}$	623

See Particle Listings for 3 decay modes that have been seen / not seen.

$\chi_{b0}(2P)$ [ggbb]

$I^G(J^{PC}) = 0^+(0^{++})$
J needs confirmation.

Mass $m = 10232.5 \pm 0.4 \pm 0.5$ MeV

$\chi_{b0}(2P)$ DECAY MODES	Fraction (Γ_i/Γ)		Confidence level	p (MeV/c)
$\gamma\Upsilon(2S)$	(1.38 ± 0.30)	%		207
$\gamma\Upsilon(1S)$	(3.8 ± 1.7)	$\times 10^{-3}$		743
$D^0 X$	$<$ 8.2	%	90%	–
$\pi^+\pi^- K^+ K^-\pi^0$	$<$ 3.4	$\times 10^{-5}$	90%	5064
$2\pi^+\pi^- K^- K_S^0$	$<$ 5	$\times 10^{-5}$	90%	5063
$2\pi^+\pi^- K^- K_S^0 2\pi^0$	$<$ 2.2	$\times 10^{-4}$	90%	5036
$2\pi^+ 2\pi^- 2\pi^0$	$<$ 2.4	$\times 10^{-4}$	90%	5092
$2\pi^+ 2\pi^- K^+ K^-$	$<$ 1.5	$\times 10^{-4}$	90%	5050
$2\pi^+ 2\pi^- K^+ K^-\pi^0$	$<$ 2.2	$\times 10^{-4}$	90%	5035
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$<$ 1.1	$\times 10^{-3}$	90%	5019
$3\pi^+ 2\pi^- K^- K_S^0\pi^0$	$<$ 7	$\times 10^{-4}$	90%	5018
$3\pi^+ 3\pi^-$	$<$ 7	$\times 10^{-5}$	90%	5091
$3\pi^+ 3\pi^- 2\pi^0$	$<$ 1.2	$\times 10^{-3}$	90%	5070
$3\pi^+ 3\pi^- K^+ K^-$	$<$ 1.5	$\times 10^{-4}$	90%	5017
$3\pi^+ 3\pi^- K^+ K^-\pi^0$	$<$ 7	$\times 10^{-4}$	90%	4999
$4\pi^+ 4\pi^-$	$<$ 1.7	$\times 10^{-4}$	90%	5069
$4\pi^+ 4\pi^- 2\pi^0$	$<$ 6	$\times 10^{-4}$	90%	5039

$\chi_{b1}(2P)$ [ggbb]

$I^G(J^{PC}) = 0^+(1^{++})$
J needs confirmation.

Mass $m = 10255.46 \pm 0.22 \pm 0.50$ MeV
$m_{\chi_{b1}(2P)} - m_{\chi_{b0}(2P)} = 23.5 \pm 1.0$ MeV

$\chi_{b1}(2P)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\omega\,\Upsilon(1S)$	$(1.63^{+0.40}_{-0.34})$ %	135
$\gamma\,\Upsilon(2S)$	(18.1 ± 1.9) %	230
$\gamma\,\Upsilon(1S)$	(9.9 ± 1.0) %	764
$\pi\pi\chi_{b1}(1P)$	$(9.1 \pm 1.3) \times 10^{-3}$	238
$D^0 X$	(8.8 ± 1.7) %	–
$\pi^+\pi^- K^+ K^- \pi^0$	$(3.1 \pm 1.0) \times 10^{-4}$	5075
$2\pi^+\pi^- K^- K^0_S$	$(1.1 \pm 0.5) \times 10^{-4}$	5075
$2\pi^+\pi^- K^- K^0_S 2\pi^0$	$(7.7 \pm 3.2) \times 10^{-4}$	5047
$2\pi^+ 2\pi^- 2\pi^0$	$(5.9 \pm 2.0) \times 10^{-4}$	5104
$2\pi^+ 2\pi^- K^+ K^-$	$(10 \pm 4) \times 10^{-5}$	5062
$2\pi^+ 2\pi^- K^+ K^- \pi^0$	$(5.5 \pm 1.8) \times 10^{-4}$	5047
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$(10 \pm 4) \times 10^{-4}$	5030
$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	$(6.7 \pm 2.6) \times 10^{-4}$	5029
$3\pi^+ 3\pi^-$	$(1.2 \pm 0.4) \times 10^{-4}$	5103
$3\pi^+ 3\pi^- 2\pi^0$	$(1.2 \pm 0.4) \times 10^{-3}$	5081
$3\pi^+ 3\pi^- K^+ K^-$	$(2.0 \pm 0.8) \times 10^{-4}$	5029
$3\pi^+ 3\pi^- K^+ K^- \pi^0$	$(6.1 \pm 2.2) \times 10^{-4}$	5011
$4\pi^+ 4\pi^-$	$(1.7 \pm 0.6) \times 10^{-4}$	5080
$4\pi^+ 4\pi^- 2\pi^0$	$(1.9 \pm 0.7) \times 10^{-3}$	5051

$\chi_{b2}(2P)$ [ggbb]

$I^G(J^{PC}) = 0^+(2^{++})$
J needs confirmation.

Mass $m = 10268.65 \pm 0.22 \pm 0.50$ MeV
$m_{\chi_{b2}(2P)} - m_{\chi_{b1}(2P)} = 13.10 \pm 0.24$ MeV

$\chi_{b2}(2P)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\omega\,\Upsilon(1S)$	$(1.10^{+0.34}_{-0.30})$ %		194
$\gamma\,\Upsilon(2S)$	(8.9 ± 1.2) %		242
$\gamma\,\Upsilon(1S)$	(6.6 ± 0.8) %		777
$\pi\pi\chi_{b2}(1P)$	$(5.1 \pm 0.9) \times 10^{-3}$		229
$D^0 X$	< 2.4 %	90%	–
$\pi^+\pi^- K^+ K^- \pi^0$	$< 1.1 \times 10^{-4}$	90%	5082
$2\pi^+\pi^- K^- K^0_S$	$< 9 \times 10^{-5}$	90%	5082
$2\pi^+\pi^- K^- K^0_S 2\pi^0$	$< 7 \times 10^{-4}$	90%	5054
$2\pi^+ 2\pi^- 2\pi^0$	$(3.9 \pm 1.6) \times 10^{-4}$		5110
$2\pi^+ 2\pi^- K^+ K^-$	$(9 \pm 4) \times 10^{-5}$		5068
$2\pi^+ 2\pi^- K^+ K^- \pi^0$	$(2.4 \pm 1.1) \times 10^{-4}$		5054
$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$(4.7 \pm 2.3) \times 10^{-4}$		5037
$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	$< 4 \times 10^{-4}$	90%	5036
$3\pi^+ 3\pi^-$	$(9 \pm 4) \times 10^{-5}$		5110
$3\pi^+ 3\pi^- 2\pi^0$	$(1.2 \pm 0.4) \times 10^{-3}$		5088
$3\pi^+ 3\pi^- K^+ K^-$	$(1.4 \pm 0.7) \times 10^{-4}$		5036
$3\pi^+ 3\pi^- K^+ K^- \pi^0$	$(4.2 \pm 1.7) \times 10^{-4}$		5017
$4\pi^+ 4\pi^-$	$(9 \pm 5) \times 10^{-5}$		5087
$4\pi^+ 4\pi^- 2\pi^0$	$(1.3 \pm 0.5) \times 10^{-3}$		5058

$\Upsilon(3S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 10355.2 \pm 0.5$ MeV
$m_{\Upsilon(3S)} - m_{\Upsilon(2S)} = 331.50 \pm 0.13$ MeV
Full width $\Gamma = 20.32 \pm 1.85$ keV
$\Gamma_{ee} = 0.443 \pm 0.008$ keV

$\Upsilon(3S)$ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\Upsilon(2S)$ anything		(10.6 ± 0.8) %		296
$\Upsilon(2S)\pi^+\pi^-$		(2.82 ± 0.18) %	S=1.6	177
$\Upsilon(2S)\pi^0\pi^0$		(1.85 ± 0.14) %		190
$\Upsilon(2S)\gamma\gamma$		(5.0 ± 0.7) %		327
$\Upsilon(2S)\pi^0$		$< 5.1 \times 10^{-4}$	CL=90%	298
$\Upsilon(1S)\pi^+\pi^-$		(4.37 ± 0.08) %		813
$\Upsilon(1S)\pi^0\pi^0$		(2.20 ± 0.13) %		816
$\Upsilon(1S)\eta$		$< 1 \times 10^{-4}$	CL=90%	677
$\Upsilon(1S)\pi^0$		$< 7 \times 10^{-5}$	CL=90%	846
$h_b(1P)\pi^0$		$< 1.2 \times 10^{-3}$	CL=90%	426
$h_b(1P)\pi^0 \to \gamma\eta_b(1S)\pi^0$		$(4.3 \pm 1.4) \times 10^{-4}$		–
$h_b(1P)\pi^+\pi^-$		$< 1.2 \times 10^{-4}$	CL=90%	353
$\tau^+\tau^-$		(2.29 ± 0.30) %		4863
$\mu^+\mu^-$		(2.18 ± 0.21) %	S=2.1	5177
e^+e^-		(2.18 ± 0.20) %		5178
hadrons		(93 ± 12) %		–
ggg		(35.7 ± 2.6) %		–
γgg		$(9.7 \pm 1.8) \times 10^{-3}$		–
^2H anything		$(2.33 \pm 0.33) \times 10^{-5}$		–
Radiative decays				
$\gamma\chi_{b2}(2P)$		(13.1 ± 1.6) %	S=3.4	86
$\gamma\chi_{b1}(2P)$		(12.6 ± 1.2) %	S=2.4	99
$\gamma\chi_{b0}(2P)$		(5.9 ± 0.6) %	S=1.4	122
$\gamma\chi_{b2}(1P)$		$(9.9 \pm 1.2) \times 10^{-3}$	S=1.9	434
$\gamma\chi_{b1}(1P)$		$(9 \pm 5) \times 10^{-4}$	S=1.8	452
$\gamma\chi_{b0}(1P)$		$(2.7 \pm 0.4) \times 10^{-3}$		484
$\gamma\eta_b(2S)$		$< 6.2 \times 10^{-4}$	CL=90%	350
$\gamma\eta_b(1S)$		$(5.1 \pm 0.7) \times 10^{-4}$		912
$\gamma A^0 \to \gamma$ hadrons		$< 8 \times 10^{-5}$	CL=90%	–
$\gamma X \to \gamma + \geq 4$ prongs	[iibb]	$< 2.2 \times 10^{-4}$	CL=95%	–
$\gamma a_1^0 \to \gamma\mu^+\mu^-$		$< 5.5 \times 10^{-6}$	CL=90%	–
$\gamma a_1^0 \to \gamma\tau^+\tau^-$	[jjbb]	$< 1.6 \times 10^{-4}$	CL=90%	–
Lepton Family number (*LF*) violating modes				
$e^\pm\tau^\mp$	*LF*	$< 4.2 \times 10^{-6}$	CL=90%	5025
$\mu^\pm\tau^\mp$	*LF*	$< 3.1 \times 10^{-6}$	CL=90%	5025

$\chi_{b1}(3P)$

$I^G(J^{PC}) = 0^+(1^{++})$

Mass $m = 10512.1 \pm 2.3$ MeV

$\Upsilon(4S)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 10579.4 \pm 1.2$ MeV
Full width $\Gamma = 20.5 \pm 2.5$ MeV
$\Gamma_{ee} = 0.272 \pm 0.029$ keV (S = 1.5)

$\Upsilon(4S)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$B\overline{B}$	> 96 %	95%	326
B^+B^-	(51.4 ± 0.6) %		331
D_s^+ anything + c.c.	(17.8 ± 2.6) %		–
$B^0\overline{B}^0$	(48.6 ± 0.6) %		326
$J/\psi K_S^0 + (J/\psi, \eta_c) K_S^0$	$< 4 \times 10^{-7}$	90%	–
non-$B\overline{B}$	< 4 %	95%	–
e^+e^-	$(1.57 \pm 0.08) \times 10^{-5}$		5290
$\rho^+\rho^-$	$< 5.7 \times 10^{-6}$	90%	5233
$K^*(892)^0\overline{K}^0$	$< 2.0 \times 10^{-6}$	90%	5240
$J/\psi(1S)$ anything	$< 1.9 \times 10^{-4}$	95%	–
D^{*+} anything + c.c.	< 7.4 %	90%	5099
ϕ anything	(7.1 ± 0.6) %		5240
$\phi\eta$	$< 1.8 \times 10^{-6}$	90%	5226
$\phi\eta'$	$< 4.3 \times 10^{-6}$	90%	5196
$\rho\eta$	$< 1.3 \times 10^{-6}$	90%	5247
$\rho\eta'$	$< 2.5 \times 10^{-6}$	90%	5217
$\Upsilon(1S)$ anything	$< 4 \times 10^{-3}$	90%	1053
$\Upsilon(1S)\pi^+\pi^-$	$(8.2 \pm 0.4) \times 10^{-5}$		1026
$\Upsilon(1S)\eta$	$(1.81 \pm 0.18) \times 10^{-4}$		924
$\Upsilon(2S)\pi^+\pi^-$	$(8.2 \pm 0.8) \times 10^{-5}$		468
$h_b(1P)\eta$	$(2.18 \pm 0.21) \times 10^{-3}$		390
$^2\overline{H}$ anything	$< 1.3 \times 10^{-5}$	90%	–
Double Radiative Decays			
$\gamma\gamma\Upsilon(\mathrm{D}) \to \gamma\gamma\eta\Upsilon(1S)$	$< 2.3 \times 10^{-5}$	90%	–

See Particle Listings for 1 decay modes that have been seen / not seen.

$Z_b(10610)$

$I^G(J^{PC}) = 1^+(1^{+-})$

Mass $m = 10607.2 \pm 2.0$ MeV
Full width $\Gamma = 18.4 \pm 2.4$ MeV

$Z_b(10610)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Upsilon(1S)\pi^+$	$(5.4^{+1.9}_{-1.5}) \times 10^{-3}$	1077
$\Upsilon(2S)\pi^+$	$(3.6^{+1.1}_{-0.8})$ %	551
$\Upsilon(3S)\pi^+$	$(2.1^{+0.8}_{-0.6})$ %	207
$h_b(1P)\pi^+$	$(3.5^{+1.2}_{-0.9})$ %	671
$h_b(2P)\pi^+$	$(4.7^{+1.7}_{-1.3})$ %	313
$B^+\overline{B}^{*0} + B^{*+}\overline{B}^0$	$(85.6^{+2.1}_{-2.9})$ %	–

See Particle Listings for 5 decay modes that have been seen / not seen.

$\Upsilon(10860)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 10889.9^{+3.2}_{-2.6}$ MeV
Full width $\Gamma = 51^{+6}_{-7}$ MeV
$\Gamma_{ee} = 0.31 \pm 0.07$ keV (S = 1.3)

$\Upsilon(10860)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$B\overline{B}X$	$(76.2\ ^{+2.7}_{-4.0})$ %		–
$B\overline{B}$	(5.5 ± 1.0) %		1332
$B\overline{B}^* +$ c.c.	(13.7 ± 1.6) %		–
$B^*\overline{B}^*$	(38.1 ± 3.4) %		1138
$B\overline{B}^{(*)}\pi$	< 19.7 %	90%	1027
$B\overline{B}\pi$	(0.0 ± 1.2) %		1027
$B^*\overline{B}\pi + B\overline{B}^*\pi$	(7.3 ± 2.3) %		–
$B^*\overline{B}^*\pi$	(1.0 ± 1.4) %		756
$B\overline{B}\pi\pi$	< 8.9 %	90%	574
$B_s^{(*)}\overline{B}_s^{(*)}$	(20.1 ± 3.1) %		919
$B_s\overline{B}_s$	$(5 \pm 5) \times 10^{-3}$		919
$B_s\overline{B}_s^* +$ c.c.	(1.35 ± 0.32) %		–
$B_s^*\overline{B}_s^*$	(17.6 ± 2.7) %		566
no open-bottom	$(3.8\ ^{+5.0}_{-0.5})$ %		–
e^+e^-	$(6.1 \pm 1.6) \times 10^{-6}$		5445
$K^*(892)^0\overline{K}^0$	$< 1.0 \times 10^{-5}$	90%	5397
$\Upsilon(1S)\pi^+\pi^-$	$(5.3 \pm 0.6) \times 10^{-3}$		1310
$\Upsilon(2S)\pi^+\pi^-$	$(7.8 \pm 1.3) \times 10^{-3}$		788
$\Upsilon(3S)\pi^+\pi^-$	$(4.8\ ^{+1.9}_{-1.7}) \times 10^{-3}$		445
$\Upsilon(1S)K^+K^-$	$(6.1 \pm 1.8) \times 10^{-4}$		965
$h_b(1P)\pi^+\pi^-$	$(3.5\ ^{+1.0}_{-1.3}) \times 10^{-3}$		907
$h_b(2P)\pi^+\pi^-$	$(5.7\ ^{+1.7}_{-2.1}) \times 10^{-3}$		548
$\chi_{b0}(1P)\pi^+\pi^-\pi^0$	$< 6.3 \times 10^{-3}$	90%	899
$\chi_{b0}(1P)\omega$	$< 3.9 \times 10^{-3}$	90%	638
$\chi_{b0}(1P)(\pi^+\pi^-\pi^0)_{\text{non}-\omega}$	$< 4.8 \times 10^{-3}$	90%	–
$\chi_{b1}(1P)\pi^+\pi^-\pi^0$	$(1.85 \pm 0.33) \times 10^{-3}$		865
$\chi_{b1}(1P)\omega$	$(1.57 \pm 0.30) \times 10^{-3}$		589
$\chi_{b1}(1P)(\pi^+\pi^-\pi^0)_{\text{non}-\omega}$	$(5.2 \pm 1.9) \times 10^{-4}$		–
$\chi_{b2}(1P)\pi^+\pi^-\pi^0$	$(1.17 \pm 0.30) \times 10^{-3}$		846
$\chi_{b2}(1P)\omega$	$(6.0 \pm 2.7) \times 10^{-4}$		559
$\chi_{b2}(1P)(\pi^+\pi^-\pi^0)_{\text{non}-\omega}$	$(6 \pm 4) \times 10^{-4}$		–
$\gamma X_b \to \gamma\Upsilon(1S)\omega$	$< 3.8 \times 10^{-5}$	90%	–

Inclusive Decays.

These decay modes are submodes of one or more of the decay modes above.

ϕ anything	$(13.8\ ^{+2.4}_{-1.7})$ %		–
D^0 anything + c.c.	(108 ± 8) %		–
D_s anything + c.c.	(46 ± 6) %		–
J/ψ anything	(2.06 ± 0.21) %		–
B^0 anything + c.c.	(77 ± 8) %		–
B^+ anything + c.c.	(72 ± 6) %		–

$\Upsilon(11020)$

$I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 10992.9^{+10.0}_{-3.1}$ MeV
Full width $\Gamma = 49^{+9}_{-15}$ MeV
$\Gamma_{ee} = 0.130 \pm 0.030$ keV

$\Upsilon(11020)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
e^+e^-	$(2.7^{+1.0}_{-0.8}) \times 10^{-6}$	5496

NOTES

In this Summary Table:

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as $S = \sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame.

[*a*] See the "Note on $\pi^\pm \to \ell^\pm \nu\gamma$ and $K^\pm \to \ell^\pm \nu\gamma$ Form Factors" in the $\pi^\pm$ Particle Listings in the Full *Review of Particle Physics* for definitions and details.

[*b*] Measurements of $\Gamma(e^+\nu_e)/\Gamma(\mu^+\nu_\mu)$ always include decays with γ's, and measurements of $\Gamma(e^+\nu_e\gamma)$ and $\Gamma(\mu^+\nu_\mu\gamma)$ never include low-energy γ's. Therefore, since no clean separation is possible, we consider the modes with γ's to be subreactions of the modes without them, and let $[\Gamma(e^+\nu_e) + \Gamma(\mu^+\nu_\mu)]/\Gamma_{\text{total}} = 100\%$.

[*c*] See the $\pi^\pm$ Particle Listings in the Full *Review of Particle Physics* for the energy limits used in this measurement; low-energy γ's are not included.

[*d*] Derived from an analysis of neutrino-oscillation experiments.

[*e*] Astrophysical and cosmological arguments give limits of order 10^{-13}; see the π^0 Particle Listings in the Full *Review of Particle Physics*.

[*f*] C parity forbids this to occur as a single-photon process.

[*g*] See the "Note on scalar mesons" in the $f_0(500)$ Particle Listings in the Full *Review of Particle Physics*. The interpretation of this entry as a particle is controversial.

[*h*] See the "Note on $\rho(770)$" in the $\rho(770)$ Particle Listings in the Full *Review of Particle Physics*.

[*i*] The $\omega\rho$ interference is then due to $\omega\rho$ mixing only, and is expected to be small. If $e\mu$ universality holds, $\Gamma(\rho^0 \to \mu^+\mu^-) = \Gamma(\rho^0 \to e^+e^-) \times 0.99785$.

[*j*] See the "Note on scalar mesons" in the $f_0(500)$ Particle Listings in the Full *Review of Particle Physics*.

[*k*] See the "Note on $a_1(1260)$" in the $a_1(1260)$ Particle Listings in PDG 06, Journal of Physics **G33** 1 (2006).

[*l*] This is only an educated guess; the error given is larger than the error on the average of the published values. See the Particle Listings in the Full *Review of Particle Physics* for details.

[*n*] See the "Note on non-$q\overline{q}$ mesons" in the Particle Listings in PDG 06, Journal of Physics **G33** 1 (2006).

[o] See the "Note on the $\eta(1405)$" in the $\eta(1405)$ Particle Listings in the Full *Review of Particle Physics*.

[p] See the "Note on the $f_1(1420)$" in the $\eta(1405)$ Particle Listings in the Full *Review of Particle Physics*.

[q] See also the $\omega(1650)$ Particle Listings.

[r] See the "Note on the $\rho(1450)$ and the $\rho(1700)$" in the $\rho(1700)$ Particle Listings in the Full *Review of Particle Physics*.

[s] See also the $\omega(1420)$ Particle Listings.

[t] See the "Note on $f_0(1710)$" in the $f_0(1710)$ Particle Listings in 2004 edition of *Review of Particle Physics*.

[u] See the note in the $K^\pm$ Particle Listings in the Full *Review of Particle Physics*.

[v] Neglecting photon channels. See, *e.g.*, A. Pais and S.B. Treiman, Phys. Rev. **D12**, 2744 (1975).

[x] The definition of the slope parameters of the $K \rightarrow 3\pi$ Dalitz plot is as follows (see also "Note on Dalitz Plot Parameters for $K \rightarrow 3\pi$ Decays" in the $K^\pm$ Particle Listings in the Full *Review of Particle Physics*):

$$|M|^2 = 1 + g(s_3 - s_0)/m^2_{\pi^+} + \cdots .$$

[y] For more details and definitions of parameters see Particle Listings in the Full *Review of Particle Physics*.

[z] See the $K^\pm$ Particle Listings in the Full *Review of Particle Physics* for the energy limits used in this measurement.

[aa] Most of this radiative mode, the low-momentum γ part, is also included in the parent mode listed without γ's.

[bb] Structure-dependent part.

[cc] Direct-emission branching fraction.

[dd] Violates angular-momentum conservation.

[ee] Derived from measured values of ϕ_{+-}, ϕ_{00}, $|\eta|$, $|m_{K^0_L} - m_{K^0_S}|$, and $\tau_{K^0_S}$, as described in the introduction to "Tests of Conservation Laws."

[ff] The *CP*-violation parameters are defined as follows (see also "Note on *CP* Violation in $K_S \rightarrow 3\pi$" and "Note on *CP* Violation in K^0_L Decay" in the Particle Listings in the Full *Review of Particle Physics*):

$$\eta_{+-} = |\eta_{+-}|e^{i\phi_{+-}} = \frac{A(K^0_L \rightarrow \pi^+\pi^-)}{A(K^0_S \rightarrow \pi^+\pi^-)} = \epsilon + \epsilon'$$

$$\eta_{00} = |\eta_{00}|e^{i\phi_{00}} = \frac{A(K^0_L \rightarrow \pi^0\pi^0)}{A(K^0_S \rightarrow \pi^0\pi^0)} = \epsilon - 2\epsilon'$$

$$\delta = \frac{\Gamma(K^0_L \rightarrow \pi^-\ell^+\nu) - \Gamma(K^0_L \rightarrow \pi^+\ell^-\nu)}{\Gamma(K^0_L \rightarrow \pi^-\ell^+\nu) + \Gamma(K^0_L \rightarrow \pi^+\ell^-\nu)} ,$$

$$\mathrm{Im}(\eta_{+-0})^2 = \frac{\Gamma(K^0_S \rightarrow \pi^+\pi^-\pi^0)^{CP\ \text{viol.}}}{\Gamma(K^0_L \rightarrow \pi^+\pi^-\pi^0)} ,$$

$$\mathrm{Im}(\eta_{000})^2 = \frac{\Gamma(K^0_S \rightarrow \pi^0\pi^0\pi^0)}{\Gamma(K^0_L \rightarrow \pi^0\pi^0\pi^0)} .$$

where for the last two relations *CPT* is assumed valid, *i.e.*, $\mathrm{Re}(\eta_{+-0}) \simeq 0$ and $\mathrm{Re}(\eta_{000}) \simeq 0$.

[gg] See the K^0_S Particle Listings in the Full *Review of Particle Physics* for the energy limits used in this measurement.

[*hh*] The value is for the sum of the charge states or particle/antiparticle states indicated.

[*ii*] $\mathrm{Re}(\epsilon'/\epsilon) = \epsilon'/\epsilon$ to a very good approximation provided the phases satisfy *CPT* invariance.

[*jj*] This mode includes gammas from inner bremsstrahlung but not the direct emission mode $K_L^0 \to \pi^+\pi^-\gamma(\mathrm{DE})$.

[*kk*] See the K_L^0 Particle Listings in the Full *Review of Particle Physics* for the energy limits used in this measurement.

[*ll*] Allowed by higher-order electroweak interactions.

[*nn*] Violates *CP* in leading order. Test of direct *CP* violation since the indirect *CP*-violating and *CP*-conserving contributions are expected to be suppressed.

[*oo*] See the "Note on $f_0(1370)$" in the $f_0(1370)$ Particle Listings in the Full *Review of Particle Physics* and in the 1994 edition.

[*pp*] See the note in the $L(1770)$ Particle Listings in Reviews of Modern Physics **56** S1 (1984), p. S200. See also the "Note on $K_2(1770)$ and the $K_2(1820)$" in the $K_2(1770)$ Particle Listings in the Full *Review of Particle Physics*.

[*qq*] See the "Note on $K_2(1770)$ and the $K_2(1820)$" in the $K_2(1770)$ Particle Listings in the Full *Review of Particle Physics*.

[*rr*] This result applies to $Z^0 \to c\overline{c}$ decays only. Here ℓ^+ is an average (not a sum) of e^+ and μ^+ decays.

[*ss*] See the Particle Listings for the (complicated) definition of this quantity.

[*tt*] The branching fraction for this mode may differ from the sum of the submodes that contribute to it, due to interference effects. See the relevant papers in the Particle Listings in the Full *Review of Particle Physics*.

[*uu*] These subfractions of the $K^- 2\pi^+$ mode are uncertain: see the Particle Listings.

[*vv*] Submodes of the $D^+ \to K^- 2\pi^+\pi^0$ and $K_S^0 2\pi^+\pi^-$ modes were studied by ANJOS 92C and COFFMAN 92B, but with at most 142 events for the first mode and 229 for the second – not enough for precise results. With nothing new for 18 years, we refer to our 2008 edition, Physics Letters **B667** 1 (2008), for those results.

[*xx*] The unseen decay modes of the resonances are included.

[*yy*] This is *not* a test for the ΔC=1 weak neutral current, but leads to the $\pi^+\ell^+\ell^-$ final state.

[*zz*] This mode is not a useful test for a ΔC=1 weak neutral current because both quarks must change flavor in this decay.

[*aaa*] In the 2010 *Review*, the values for these quantities were given using a measure of the asymmetry that was inconsistent with the usual definition.

[*bbb*] This value is obtained by subtracting the branching fractions for 2-, 4- and 6-prongs from unity.

[*ccc*] This is the sum of our $K^- 2\pi^+\pi^-$, $K^- 2\pi^+\pi^-\pi^0$, $\overline{K}^0 2\pi^+ 2\pi^-$, $K^+ 2K^-\pi^+$, $2\pi^+ 2\pi^-$, $2\pi^+ 2\pi^-\pi^0$, $K^+ K^-\pi^+\pi^-$, and $K^+ K^-\pi^+\pi^-\pi^0$, branching fractions.

[*ddd*] This is the sum of our $K^- 3\pi^+ 2\pi^-$ and $3\pi^+ 3\pi^-$ branching fractions.

[*eee*] The branching fractions for the $K^- e^+\nu_e$, $K^*(892)^- e^+\nu_e$, $\pi^- e^+\nu_e$, and $\rho^- e^+\nu_e$ modes add up to 6.19 ± 0.17 %.

[*fff*] This is a doubly Cabibbo-suppressed mode.

[ggg] Submodes of the $D^0 \rightarrow K_S^0 \pi^+ \pi^- \pi^0$ mode with a K^* and/or ρ were studied by COFFMAN 92B, but with only 140 events. With nothing new for 18 years, we refer to our 2008 edition, Physics Letters **B667** 1 (2008), for those results.

[hhh] This branching fraction includes all the decay modes of the resonance in the final state.

[iii] This limit is for either D^0 or $\overline{D}^0$ to $p e^-$.

[jjj] This limit is for either D^0 or $\overline{D}^0$ to $\overline{p} e^+$.

[kkk] This is the purely e^+ semileptonic branching fraction: the e^+ fraction from τ^+ decays has been subtracted off. The sum of our (non-τ) e^+ exclusive fractions — an $e^+ \nu_e$ with an η, η', ϕ, K^0, or K^{*0} — is 5.99 ± 0.31 %.

[lll] This fraction includes η from η' decays.

[nnn] The sum of our exclusive η' fractions — $\eta' e^+ \nu_e$, $\eta' \mu^+ \nu_\mu$, $\eta' \pi^+$, $\eta' \rho^+$, and $\eta' K^+$ — is $11.8 \pm 1.6\%$.

[ooo] This branching fraction includes all the decay modes of the final-state resonance.

[ppp] A test for $u\overline{u}$ or $d\overline{d}$ content in the D_s^+. Neither Cabibbo-favored nor Cabibbo-suppressed decays can contribute, and $\omega - \phi$ mixing is an unlikely explanation for any fraction above about 2×10^{-4}.

[qqq] We decouple the $D_s^+ \rightarrow \phi\pi^+$ branching fraction obtained from mass projections (and used to get some of the other branching fractions) from the $D_s^+ \rightarrow \phi\pi^+$, $\phi \rightarrow K^+ K^-$ branching fraction obtained from the Dalitz-plot analysis of $D_s^+ \rightarrow K^+ K^- \pi^+$. That is, the ratio of these two branching fractions is not exactly the $\phi \rightarrow K^+ K^-$ branching fraction 0.491.

[rrr] This is the average of a model-independent and a K-matrix parametrization of the $\pi^+ \pi^-$ S-wave and is a sum over several f_0 mesons.

[sss] An ℓ indicates an e or a μ mode, not a sum over these modes.

[ttt] An $CP(\pm1)$ indicates the CP=+1 and CP=−1 eigenstates of the D^0-$\overline{D}^0$ system.

[uuu] D denotes D^0 or $\overline{D}^0$.

[vvv] D^{*0}_{CP+} decays into $D^0 \pi^0$ with the D^0 reconstructed in CP-even eigenstates $K^+ K^-$ and $\pi^+ \pi^-$.

[xxx] $\overline{D}^{**}$ represents an excited state with mass $2.2 < \mathrm{M} < 2.8$ GeV/c^2.

[yyy] $\chi_{c1}(3872)^+$ is a hypothetical charged partner of the $\chi_{c1}(3872)$.

[zzz] $\Theta(1710)^{++}$ is a possible narrow pentaquark state and $G(2220)$ is a possible glueball resonance.

[aaaa] $(\overline{\Lambda}_c^- p)_s$ denotes a low-mass enhancement near 3.35 GeV/c^2.

[bbaa] Stands for the possible candidates of $K^*(1410)$, $K_0^*(1430)$ and $K_2^*(1430)$.

[ccaa] B^0 and B_s^0 contributions not separated. Limit is on weighted average of the two decay rates.

[ddaa] This decay refers to the coherent sum of resonant and nonresonant $J^P = 0^+$ $K\pi$ components with $1.60 < m_{K\pi} < 2.15$ GeV/c^2.

[eeaa] $X(214)$ is a hypothetical particle of mass 214 MeV/c^2 reported by the HyperCP experiment, Physical Review Letters **94** 021801 (2005)

[ffaa] $\Theta(1540)^+$ denotes a possible narrow pentaquark state.

[*ggaa*] Here S and P are the hypothetical scalar and pseudoscalar particles with masses of 2.5 GeV/c^2 and 214.3 MeV/c^2, respectively.

[*hhaa*] These values are model dependent.

[*iiaa*] Here "anything" means at least one particle observed.

[*jjaa*] This is a B($B^0 \rightarrow D^{*-} \ell^+ \nu_\ell$) value.

[*kkaa*] D^{**} stands for the sum of the $D(1\,^1P_1)$, $D(1\,^3P_0)$, $D(1\,^3P_1)$, $D(1\,^3P_2)$, $D(2\,^1S_0)$, and $D(2\,^1S_1)$ resonances.

[*llaa*] $D^{(*)}\overline{D}^{(*)}$ stands for the sum of $D^*\overline{D}^*$, $D^*\overline{D}$, $D\overline{D}^*$, and $D\overline{D}$.

[*nnaa*] $X(3915)$ denotes a near-threshold enhancement in the $\omega J/\psi$ mass spectrum.

[*ooaa*] Inclusive branching fractions have a multiplicity definition and can be greater than 100%.

[*ppaa*] D_j represents an unresolved mixture of pseudoscalar and tensor D^{**} (P-wave) states.

[*qqaa*] Not a pure measurement. See note at head of B_s^0 Decay Modes.

[*rraa*] For $E_\gamma > 100$ MeV.

[*ssaa*] Includes $p\overline{p}\pi^+\pi^-\gamma$ and excludes $p\overline{p}\eta$, $p\overline{p}\omega$, $p\overline{p}\eta'$.

[*ttaa*] For a narrow state A with mass less than 960 MeV.

[*uuaa*] For a narrow scalar or pseudoscalar A^0 with mass 0.21–3.0 GeV.

[*vvaa*] For a narrow resonance in the range $2.2 < M(X) < 2.8$ GeV.

[*xxaa*] J^{PC} known by production in e^+e^- via single photon annihilation. I^G is not known; interpretation of this state as a single resonance is unclear because of the expectation of substantial threshold effects in this energy region.

[*yyaa*] $2m_\tau < \mathrm{M}(\tau^+\tau^-) < 9.2$ GeV

[*zzaa*] 2 GeV $< m_{K^+K^-} <$ 3 GeV

[*aabb*] X = scalar with $m < 8.0$ GeV

[*bbbb*] $X\overline{X}$ = vectors with $m < 3.1$ GeV

[*ccbb*] X and $\overline{X}$ = zero spin with $m < 4.5$ GeV

[*ddbb*] 1.5 GeV $< m_X <$ 5.0 GeV

[*eebb*] 201 MeV $< \mathrm{M}(\mu^+\mu^-) <$ 3565 MeV

[*ffbb*] 0.5 GeV $< m_X <$ 9.0 GeV, where m_X is the invariant mass of the hadronic final state.

[*ggbb*] Spectroscopic labeling for these states is theoretical, pending experimental information.

[*hhbb*] 1.5 GeV $< m_X <$ 5.0 GeV

[*iibb*] 1.5 GeV $< m_X <$ 5.0 GeV

[*jjbb*] For $m_{\tau^+\tau^-}$ in the ranges 4.03–9.52 and 9.61–10.10 GeV.

N BARYONS
$(S = 0, I = 1/2)$

$p, N^+ = uud; \quad n, N^0 = udd$

p

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Mass $m = 1.00727646688 \pm 0.00000000009$ u

Mass $m = 938.272081 \pm 0.000006$ MeV [a]

$|m_p - m_{\overline{p}}|/m_p < 7 \times 10^{-10}$, CL = 90% [b]

$|\frac{q_{\overline{p}}}{m_{\overline{p}}}|/(\frac{q_p}{m_p}) = 1.00000000000 \pm 0.00000000007$

$|q_p + q_{\overline{p}}|/e < 7 \times 10^{-10}$, CL = 90% [b]

$|q_p + q_e|/e < 1 \times 10^{-21}$ [c]

Magnetic moment $\mu = 2.7928473446 \pm 0.0000000008\ \mu_N$

$(\mu_p + \mu_{\overline{p}}) / \mu_p = (0.3 \pm 0.8) \times 10^{-6}$

Electric dipole moment $d < 0.021 \times 10^{-23}$ e cm

Electric polarizability $\alpha = (11.2 \pm 0.4) \times 10^{-4}$ fm^3

Magnetic polarizability $\beta = (2.5 \pm 0.4) \times 10^{-4}$ fm^3 (S = 1.2)

Charge radius, μp Lamb shift = 0.84087 ± 0.00039 fm [d]

Charge radius, ep CODATA value = 0.8751 ± 0.0061 fm [d]

Magnetic radius = 0.78 ± 0.04 fm [e]

Mean life $\tau > 2.1 \times 10^{29}$ years, CL = 90% [f] ($p \to$ invisible mode)

Mean life $\tau > 10^{31}$ to 10^{33} years [f] (mode dependent)

See the "Note on Nucleon Decay" in our 1994 edition (Phys. Rev. **D50**, 1173) for a short review.

The "partial mean life" limits tabulated here are the limits on τ/B_i, where τ is the total mean life and B_i is the branching fraction for the mode in question. For N decays, p and n indicate proton and neutron partial lifetimes.

p DECAY MODES	Partial mean life (10^{30} years)	Confidence level	p (MeV/c)
Antilepton + meson			
$N \to e^+\pi$	> 2000 (n), > 8200 (p)	90%	459
$N \to \mu^+\pi$	> 1000 (n), > 6600 (p)	90%	453
$N \to \nu\pi$	> 1100 (n), > 390 (p)	90%	459
$p \to e^+\eta$	> 4200	90%	309
$p \to \mu^+\eta$	> 1300	90%	297
$n \to \nu\eta$	> 158	90%	310
$N \to e^+\rho$	> 217 (n), > 710 (p)	90%	149
$N \to \mu^+\rho$	> 228 (n), > 160 (p)	90%	113
$N \to \nu\rho$	> 19 (n), > 162 (p)	90%	149
$p \to e^+\omega$	> 320	90%	143
$p \to \mu^+\omega$	> 780	90%	105
$n \to \nu\omega$	> 108	90%	144
$N \to e^+K$	> 17 (n), > 1000 (p)	90%	339
$N \to \mu^+K$	> 26 (n), > 1600 (p)	90%	329
$N \to \nu K$	> 86 (n), > 5900 (p)	90%	339
$n \to \nu K^0_S$	> 260	90%	338
$p \to e^+K^*(892)^0$	> 84	90%	45
$N \to \nu K^*(892)$	> 78 (n), > 51 (p)	90%	45

Antilepton + mesons			
$p \to e^+ \pi^+ \pi^-$	> 82	90%	448
$p \to e^+ \pi^0 \pi^0$	> 147	90%	449
$n \to e^+ \pi^- \pi^0$	> 52	90%	449
$p \to \mu^+ \pi^+ \pi^-$	> 133	90%	425
$p \to \mu^+ \pi^0 \pi^0$	> 101	90%	427
$n \to \mu^+ \pi^- \pi^0$	> 74	90%	427
$n \to e^+ K^0 \pi^-$	> 18	90%	319
Lepton + meson			
$n \to e^- \pi^+$	> 65	90%	459
$n \to \mu^- \pi^+$	> 49	90%	453
$n \to e^- \rho^+$	> 62	90%	150
$n \to \mu^- \rho^+$	> 7	90%	115
$n \to e^- K^+$	> 32	90%	340
$n \to \mu^- K^+$	> 57	90%	330
Lepton + mesons			
$p \to e^- \pi^+ \pi^+$	> 30	90%	448
$n \to e^- \pi^+ \pi^0$	> 29	90%	449
$p \to \mu^- \pi^+ \pi^+$	> 17	90%	425
$n \to \mu^- \pi^+ \pi^0$	> 34	90%	427
$p \to e^- \pi^+ K^+$	> 75	90%	320
$p \to \mu^- \pi^+ K^+$	> 245	90%	279
Antilepton + photon(s)			
$p \to e^+ \gamma$	> 670	90%	469
$p \to \mu^+ \gamma$	> 478	90%	463
$n \to \nu \gamma$	> 550	90%	470
$p \to e^+ \gamma \gamma$	> 100	90%	469
$n \to \nu \gamma \gamma$	> 219	90%	470
Antilepton + single massless			
$p \to e^+ X$	> 790	90%	–
$p \to \mu^+ X$	> 410	90%	–
Three (or more) leptons			
$p \to e^+ e^+ e^-$	> 793	90%	469
$p \to e^+ \mu^+ \mu^-$	> 359	90%	457
$p \to e^+ \nu \nu$	> 170	90%	469
$n \to e^+ e^- \nu$	> 257	90%	470
$n \to \mu^+ e^- \nu$	> 83	90%	464
$n \to \mu^+ \mu^- \nu$	> 79	90%	458
$p \to \mu^+ e^+ e^-$	> 529	90%	463
$p \to \mu^+ \mu^+ \mu^-$	> 675	90%	439
$p \to \mu^+ \nu \nu$	> 220	90%	463
$p \to e^- \mu^+ \mu^+$	> 6	90%	457
$n \to 3\nu$	$> 5 \times 10^{-4}$	90%	470
Inclusive modes			
$N \to e^+$ anything	> 0.6 (n, p)	90%	–
$N \to \mu^+$ anything	> 12 (n, p)	90%	–
$N \to e^+ \pi^0$ anything	> 0.6 (n, p)	90%	–
$\Delta B = 2$ dinucleon modes			
The following are lifetime limits per iron nucleus.			
$pp \to \pi^+ \pi^+$	> 72.2	90%	–
$pn \to \pi^+ \pi^0$	> 170	90%	–

$nn \to \pi^+\pi^-$	> 0.7	90%	–
$nn \to \pi^0\pi^0$	> 404	90%	–
$pp \to K^+K^+$	> 170	90%	–
$pp \to e^+e^+$	> 5.8	90%	–
$pp \to e^+\mu^+$	> 3.6	90%	–
$pp \to \mu^+\mu^+$	> 1.7	90%	–
$pn \to e^+\overline{\nu}$	> 260	90%	–
$pn \to \mu^+\overline{\nu}$	> 200	90%	–
$pn \to \tau^+\overline{\nu}_\tau$	> 29	90%	–
$nn \to \nu_e\overline{\nu}_e$	> 1.4	90%	–
$nn \to \nu_\mu\overline{\nu}_\mu$	> 1.4	90%	–
$pn \to$ invisible	$> 2.1 \times 10^{-5}$	90%	–
$pp \to$ invisible	$> 5 \times 10^{-5}$	90%	–

$\overline{p}$ DECAY MODES

Mode	Partial mean life (years)	Confidence level	p (MeV/c)
$\overline{p} \to e^-\gamma$	$> 7 \times 10^5$	90%	469
$\overline{p} \to \mu^-\gamma$	$> 5 \times 10^4$	90%	463
$\overline{p} \to e^-\pi^0$	$> 4 \times 10^5$	90%	459
$\overline{p} \to \mu^-\pi^0$	$> 5 \times 10^4$	90%	453
$\overline{p} \to e^-\eta$	$> 2 \times 10^4$	90%	309
$\overline{p} \to \mu^-\eta$	$> 8 \times 10^3$	90%	297
$\overline{p} \to e^-K^0_S$	> 900	90%	337
$\overline{p} \to \mu^-K^0_S$	$> 4 \times 10^3$	90%	326
$\overline{p} \to e^-K^0_L$	$> 9 \times 10^3$	90%	337
$\overline{p} \to \mu^-K^0_L$	$> 7 \times 10^3$	90%	326
$\overline{p} \to e^-\gamma\gamma$	$> 2 \times 10^4$	90%	469
$\overline{p} \to \mu^-\gamma\gamma$	$> 2 \times 10^4$	90%	463
$\overline{p} \to e^-\omega$	> 200	90%	143

n

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Mass $m = 1.0086649159 \pm 0.0000000005$ u
Mass $m = 939.565413 \pm 0.000006$ MeV [a]
$(m_n - m_{\overline{n}})/\ m_n = (9 \pm 6) \times 10^{-5}$
$m_n - m_p = 1.2933321 \pm 0.0000005$ MeV
$= 0.00138844919(45)$ u
Mean life $\tau = 880.2 \pm 1.0$ s (S = 1.9)
$c\tau = 2.6387 \times 10^8$ km
Magnetic moment $\mu = -1.9130427 \pm 0.0000005\ \mu_N$
Electric dipole moment $d < 0.30 \times 10^{-25}$ e cm, CL = 90%
Mean-square charge radius $\langle r_n^2 \rangle = -0.1161 \pm 0.0022$ fm^2 (S = 1.3)
Magnetic radius $\sqrt{\langle r_M^2 \rangle} = 0.864^{+0.009}_{-0.008}$ fm
Electric polarizability $\alpha = (11.8 \pm 1.1) \times 10^{-4}$ fm^3
Magnetic polarizability $\beta = (3.7 \pm 1.2) \times 10^{-4}$ fm^3
Charge $q = (-0.2 \pm 0.8) \times 10^{-21}$ e
Mean $n\overline{n}$-oscillation time $> 8.6 \times 10^7$ s, CL = 90% (free n)
Mean $n\overline{n}$-oscillation time $> 2.7 \times 10^8$ s, CL = 90% [g] (bound n)
Mean nn'-oscillation time > 414 s, CL = 90% [h]

$pe^-\nu_e$ decay parameters [i]

$\lambda \equiv g_A \,/\, g_V = -1.2724 \pm 0.0023$ (S = 2.2)
$A = -0.1184 \pm 0.0010$ (S = 2.4)
$B = 0.9807 \pm 0.0030$
$C = -0.2377 \pm 0.0026$
$a = -0.1059 \pm 0.0028$
$\phi_{AV} = (180.017 \pm 0.026)^\circ$ [j]
$D = (-1.2 \pm 2.0) \times 10^{-4}$ [k]
$R = 0.004 \pm 0.013$ [k]

***n* DECAY MODES**		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$pe^-\overline{\nu}_e$		100 %		1
$pe^-\overline{\nu}_e\gamma$	[l]	(9.2±0.7) $\times 10^{-3}$		1
Charge conservation (Q) violating mode				
$p\nu_e\overline{\nu}_e$	Q	< 8 $\times 10^{-27}$	68%	1

$N(1440)$ 1/2$^+$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

Re(pole position) = 1360 to 1380 (≈ 1370) MeV
−2Im(pole position) = 160 to 190 (≈ 175) MeV
Breit-Wigner mass = 1410 to 1470 (≈ 1440) MeV
Breit-Wigner full width = 250 to 450 (≈ 350) MeV

The following branching fractions are our estimates, not fits or averages.

***N*(1440) DECAY MODES**	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	55–75 %	398
$N\eta$	<1 %	†
$N\pi\pi$	17–50 %	347
$\Delta(1232)\pi$, P-wave	6–27 %	147
$N\sigma$	11–23 %	–
$p\gamma$, helicity=1/2	0.035–0.048 %	414
$n\gamma$, helicity=1/2	0.02–0.04 %	413

$N(1520)$ 3/2$^-$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$

Re(pole position) = 1505 to 1515 (≈ 1510) MeV
−2Im(pole position) = 105 to 120 (≈ 110) MeV
Breit-Wigner mass = 1510 to 1520 (≈ 1515) MeV
Breit-Wigner full width = 100 to 120 (≈ 110) MeV

The following branching fractions are our estimates, not fits or averages.

***N*(1520) DECAY MODES**	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	55–65 %	453
$N\eta$	0.07–0.09 %	142
$N\pi\pi$	25–35 %	410
$\Delta(1232)\pi$	22–34 %	225
$\Delta(1232)\pi$, S-wave	15–23 %	225
$\Delta(1232)\pi$, D-wave	7–11 %	225

$N\sigma$	<2 %	–
$p\gamma$	0.31–0.52 %	467
$p\gamma$, helicity=1/2	0.01–0.02 %	467
$p\gamma$, helicity=3/2	0.30–0.50 %	467
$n\gamma$	0.30–0.53 %	466
$n\gamma$, helicity=1/2	0.04–0.10 %	466
$n\gamma$, helicity=3/2	0.25–0.45 %	466

$N(1535)$ $1/2^-$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$

Re(pole position) = 1500 to 1520 (≈ 1510) MeV
−2Im(pole position) = 110 to 150 (≈ 130) MeV
Breit-Wigner mass = 1515 to 1545 (≈ 1530) MeV
Breit-Wigner full width = 125 to 175 (≈ 150) MeV

The following branching fractions are our estimates, not fits or averages.

***N*(1535) DECAY MODES**	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	32–52 %	464
$N\eta$	30–55 %	176
$N\pi\pi$	3–14 %	422
$\Delta(1232)\pi$, D-wave	1–4 %	240
$N\sigma$	2–10 %	–
$N(1440)\pi$	5–12 %	†
$p\gamma$, helicity=1/2	0.15–0.30 %	477
$n\gamma$, helicity=1/2	0.01–0.25 %	477

$N(1650)$ $1/2^-$, $N(1675)$ $5/2^-$, $N(1680)$ $5/2^+$, $N(1700)$ $3/2^-$, $N(1710)$ $1/2^+$, $N(1720)$ $3/2^+$, $N(1875)$ $3/2^-$, $N(1880)$ $1/2^+$, $N(1895)$ $1/2^-$, $N(1900)$ $3/2^+$ $N(2060)$ $5/2^-$, $N(2100)$ $1/2^+$, $N(2120)$ $3/2^-$, $N(2190)$ $7/2^-$, $N(2220)$ $9/2^+$ $N(2250)$ $9/2^-$, $N(2600)$ $11/2^-$

The N resonances listed above are omitted from this Booklet but not from the Summary Table in the full *Review*.

Δ BARYONS
($S = 0$, $I = 3/2$)

$\Delta^{++} = uuu$, $\Delta^{+} = uud$, $\Delta^{0} = udd$, $\Delta^{-} = ddd$

$\Delta(1232)$ $3/2^+$

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$

Re(pole position) = 1209 to 1211 (≈ 1210) MeV
−2Im(pole position) = 98 to 102 (≈ 100) MeV
Breit-Wigner mass (mixed charges) = 1230 to 1234 (≈ 1232) MeV
Breit-Wigner full width (mixed charges) = 114 to 120 (≈ 117) MeV

The following branching fractions are our estimates, not fits or averages.

Δ(1232) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	99.4 %	229
$N\gamma$	0.55–0.65 %	259
$N\gamma$, helicity=1/2	0.11–0.13 %	259
$N\gamma$, helicity=3/2	0.44–0.52 %	259
$p e^+ e^-$	$(4.2\pm0.7)\times10^{-5}$	259

$\Delta(1600)\ 3/2^+$

$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$

Re(pole position) = 1460 to 1560 (≈ 1510) MeV
−2Im(pole position) = 200 to 340 (≈ 270) MeV
Breit-Wigner mass = 1500 to 1640 (≈ 1570) MeV
Breit-Wigner full width = 200 to 300 (≈ 250) MeV

The following branching fractions are our estimates, not fits or averages.

Δ(1600) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	8–24 %	492
$N\pi\pi$	75–90 %	454
$\Delta(1232)\pi$	73–83 %	276
$\Delta(1232)\pi$, P-wave	72–82 %	276
$\Delta(1232)\pi$, F-wave	<2 %	276
$N(1440)\pi$, P-wave	15–25 %	†
$N\gamma$	0.001–0.035 %	505
$N\gamma$, helicity=1/2	0.0–0.02 %	505
$N\gamma$, helicity=3/2	0.001–0.015 %	505

$\Delta(1620)\ 1/2^-$

$I(J^P) = \frac{3}{2}(\frac{1}{2}^-)$

Re(pole position) = 1590 to 1610 (≈ 1600) MeV
−2Im(pole position) = 100 to 140 (≈ 120) MeV
Breit-Wigner mass = 1590 to 1630 (≈ 1610) MeV
Breit-Wigner full width = 110 to 150 (≈ 130) MeV

The following branching fractions are our estimates, not fits or averages.

Δ(1620) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\pi$	25–35 %	520
$N\pi\pi$	55–80 %	484
$\Delta(1232)\pi$, D-wave	52–72 %	311
$N(1440)\pi$	3–9 %	98
$N\gamma$, helicity=1/2	0.03–0.10 %	532

See Particle Listings for 2 decay modes that have been seen / not seen.

$\Delta(1700)\ 3/2^-$, $\Delta(1900)\ 1/2^-$, $\Delta(1905)\ 5/2^+$, $\Delta(1910)\ 1/2^+$, $\Delta(1920)\ 3/2^+$, $\Delta(1930)\ 5/2^-$, $\Delta(1950)\ 7/2^+$, $\Delta(2200)\ 7/2^-$, $\Delta(2420)\ 11/2^+$

The Δ resonances listed above are omitted from this Booklet but not from the Summary Table in the full *Review*.

Λ BARYONS
$(S=-1, I=0)$

$\Lambda^0 = uds$

Λ

$I(J^P) = 0(\frac{1}{2}^+)$

Mass $m = 1115.683 \pm 0.006$ MeV
$(m_\Lambda - m_{\overline{\Lambda}}) \,/\, m_\Lambda = (-0.1 \pm 1.1) \times 10^{-5}$ (S = 1.6)
Mean life $\tau = (2.632 \pm 0.020) \times 10^{-10}$ s (S = 1.6)
$(\tau_\Lambda - \tau_{\overline{\Lambda}}) \,/\, \tau_\Lambda = -0.001 \pm 0.009$
$c\tau = 7.89$ cm
Magnetic moment $\mu = -0.613 \pm 0.004\ \mu_N$
Electric dipole moment $d < 1.5 \times 10^{-16}$ $e$cm, CL = 95%

Decay parameters

$p\pi^-$	$\alpha_- = 0.642 \pm 0.013$
$\overline{p}\pi^+$	$\alpha_+ = -0.71 \pm 0.08$
$p\pi^-$	$\phi_- = (-6.5 \pm 3.5)^\circ$
"	$\gamma_- = 0.76$ [n]
"	$\Delta_- = (8 \pm 4)^\circ$ [n]
$n\pi^0$	$\alpha_0 = 0.65 \pm 0.04$
$pe^-\overline{\nu}_e$	$g_A/g_V = -0.718 \pm 0.015$ [i]

Λ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$p\pi^-$		(63.9 ± 0.5) %		101
$n\pi^0$		(35.8 ± 0.5) %		104
$n\gamma$		$(1.75 \pm 0.15) \times 10^{-3}$		162
$p\pi^-\gamma$	[o]	$(8.4 \pm 1.4) \times 10^{-4}$		101
$pe^-\overline{\nu}_e$		$(8.32 \pm 0.14) \times 10^{-4}$		163
$p\mu^-\overline{\nu}_\mu$		$(1.57 \pm 0.35) \times 10^{-4}$		131
Lepton (L) and/or Baryon (B) number violating decay modes				
$\pi^+ e^-$	L,B	$< 6 \times 10^{-7}$	90%	549
$\pi^+ \mu^-$	L,B	$< 6 \times 10^{-7}$	90%	544
$\pi^- e^+$	L,B	$< 4 \times 10^{-7}$	90%	549
$\pi^- \mu^+$	L,B	$< 6 \times 10^{-7}$	90%	544
$K^+ e^-$	L,B	$< 2 \times 10^{-6}$	90%	449
$K^+ \mu^-$	L,B	$< 3 \times 10^{-6}$	90%	441
$K^- e^+$	L,B	$< 2 \times 10^{-6}$	90%	449
$K^- \mu^+$	L,B	$< 3 \times 10^{-6}$	90%	441
$K^0_S \nu$	L,B	$< 2 \times 10^{-5}$	90%	447
$\overline{p}\pi^+$	B	$< 9 \times 10^{-7}$	90%	101

$\Lambda(1405)\ 1/2^-$

$I(J^P) = 0(\frac{1}{2}^-)$

Mass $m = 1405.1^{+1.3}_{-1.0}$ MeV
Full width $\Gamma = 50.5 \pm 2.0$ MeV
Below $\overline{K}N$ threshold

$\Lambda(1405)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Sigma\pi$	100 %	155

$\Lambda(1520)$ $3/2^-$

$I(J^P) = 0(\frac{3}{2}^-)$

Mass $m = 1519.5 \pm 1.0$ MeV [p]
Full width $\Gamma = 15.6 \pm 1.0$ MeV [p]

$\Lambda(1520)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	(45 ± 1) %	243
$\Sigma\pi$	(42 ± 1) %	268
$\Lambda\pi\pi$	(10 ± 1) %	259
$\Sigma\pi\pi$	(0.9 ± 0.1) %	169
$\Lambda\gamma$	(0.85 ± 0.15) %	350

$\Lambda(1600)$ $1/2^+$, $\Lambda(1670)$ $1/2^-$, $\Lambda(1690)$ $3/2^-$, $\Lambda(1800)$ $1/2^-$, $\Lambda(1810)$ $1/2^+$, $\Lambda(1820)$ $5/2^+$, $\Lambda(1830)$ $5/2^-$, $\Lambda(1890)$ $3/2^+$, $\Lambda(2100)$ $7/2^-$, $\Lambda(2110)$ $5/2^+$, $\Lambda(2350)$ $9/2^+$

The Λ resonances listed above are omitted from this Booklet but not from the Summary Table in the full *Review*.

Σ BARYONS
$(S=-1, I=1)$

$\Sigma^+ = uus$, $\Sigma^0 = uds$, $\Sigma^- = dds$

Σ^+

$I(J^P) = 1(\frac{1}{2}^+)$

Mass $m = 1189.37 \pm 0.07$ MeV (S = 2.2)
Mean life $\tau = (0.8018 \pm 0.0026) \times 10^{-10}$ s
$c\tau = 2.404$ cm
$(\tau_{\Sigma^+} - \tau_{\overline{\Sigma}^-}) / \tau_{\Sigma^+} = -0.0006 \pm 0.0012$
Magnetic moment $\mu = 2.458 \pm 0.010$ μ_N (S = 2.1)
$(\mu_{\Sigma^+} + \mu_{\overline{\Sigma}^-}) / \mu_{\Sigma^+} = 0.014 \pm 0.015$
$\Gamma(\Sigma^+ \to n\ell^+\nu)/\Gamma(\Sigma^- \to n\ell^-\overline{\nu}) < 0.043$

Decay parameters

$p\pi^0$	$\alpha_0 = -0.980^{+0.017}_{-0.015}$
"	$\phi_0 = (36 \pm 34)^\circ$
"	$\gamma_0 = 0.16$ [n]
"	$\Delta_0 = (187 \pm 6)^\circ$ [n]
$n\pi^+$	$\alpha_+ = 0.068 \pm 0.013$
"	$\phi_+ = (167 \pm 20)^\circ$ (S = 1.1)
"	$\gamma_+ = -0.97$ [n]
"	$\Delta_+ = (-73^{+133}_{-10})^\circ$ [n]
$p\gamma$	$\alpha_\gamma = -0.76 \pm 0.08$

Σ^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$p\pi^0$		(51.57 ± 0.30) %		189
$n\pi^+$		(48.31 ± 0.30) %		185
$p\gamma$		$(1.23\pm0.05)\times10^{-3}$		225
$n\pi^+\gamma$	[o]	$(4.5\ \pm0.5\ )\times10^{-4}$		185
$\Lambda e^+\nu_e$		$(2.0\ \pm0.5\ )\times10^{-5}$		71
$\Delta S = \Delta Q$ (SQ) violating modes or $\Delta S = 1$ weak neutral current ($S1$) modes				
$ne^+\nu_e$	SQ	$<5\times10^{-6}$	90%	224
$n\mu^+\nu_\mu$	SQ	$<3.0\times10^{-5}$	90%	202
pe^+e^-	$S1$	$<7\times10^{-6}$		225
$p\mu^+\mu^-$	$S1$	$(9\ {}^{+9}_{-8})\times10^{-8}$		121

Σ^0

$I(J^P) = 1(\frac{1}{2}^+)$

Mass $m = 1192.642 \pm 0.024$ MeV
$m_{\Sigma^-} - m_{\Sigma^0} = 4.807 \pm 0.035$ MeV (S = 1.1)
$m_{\Sigma^0} - m_\Lambda = 76.959 \pm 0.023$ MeV
Mean life $\tau = (7.4 \pm 0.7) \times 10^{-20}$ s
$c\tau = 2.22 \times 10^{-11}$ m
Transition magnetic moment $|\mu_{\Sigma\Lambda}| = 1.61 \pm 0.08\ \mu_N$

Σ^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda\gamma$		100 %		74
$\Lambda\gamma\gamma$		$<$ 3 %	90%	74
Λe^+e^-	[q]	5×10^{-3}		74

Σ^-

$I(J^P) = 1(\frac{1}{2}^+)$

Mass $m = 1197.449 \pm 0.030$ MeV (S = 1.2)
$m_{\Sigma^-} - m_{\Sigma^+} = 8.08 \pm 0.08$ MeV (S = 1.9)
$m_{\Sigma^-} - m_\Lambda = 81.766 \pm 0.030$ MeV (S = 1.2)
Mean life $\tau = (1.479 \pm 0.011) \times 10^{-10}$ s (S = 1.3)
$c\tau = 4.434$ cm
Magnetic moment $\mu = -1.160 \pm 0.025\ \mu_N$ (S = 1.7)
Σ^- charge radius $= 0.78 \pm 0.10$ fm

Decay parameters

$n\pi^-$	$\alpha_- = -0.068 \pm 0.008$
"	$\phi_- = (10 \pm 15)^\circ$
"	$\gamma_- = 0.98$ [n]
"	$\Delta_- = (249^{+\ 12}_{-120})^\circ$ [n]
$ne^-\overline{\nu}_e$	$g_A/g_V = 0.340 \pm 0.017$ [i]
"	$f_2(0)/f_1(0) = 0.97 \pm 0.14$
"	$D = 0.11 \pm 0.10$
$\Lambda e^-\overline{\nu}_e$	$g_V/g_A = 0.01 \pm 0.10$ [i] (S = 1.5)
"	$g_{WM}/g_A = 2.4 \pm 1.7$ [i]

Σ^- DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$n\pi^-$	(99.848 ± 0.005) %	193
$n\pi^-\gamma$	[o] $(4.6 \pm 0.6) \times 10^{-4}$	193
$ne^-\overline{\nu}_e$	$(1.017 \pm 0.034) \times 10^{-3}$	230
$n\mu^-\overline{\nu}_\mu$	$(4.5 \pm 0.4) \times 10^{-4}$	210
$\Lambda e^-\overline{\nu}_e$	$(5.73 \pm 0.27) \times 10^{-5}$	79

$\Sigma(1385)$ $3/2^+$

$I(J^P) = 1(\frac{3}{2}^+)$

$\Sigma(1385)^+$mass $m = 1382.80 \pm 0.35$ MeV (S = 1.9)
$\Sigma(1385)^0$ mass $m = 1383.7 \pm 1.0$ MeV (S = 1.4)
$\Sigma(1385)^-$mass $m = 1387.2 \pm 0.5$ MeV (S = 2.2)
$\Sigma(1385)^+$full width $\Gamma = 36.0 \pm 0.7$ MeV
$\Sigma(1385)^0$ full width $\Gamma = 36 \pm 5$ MeV
$\Sigma(1385)^-$full width $\Gamma = 39.4 \pm 2.1$ MeV (S = 1.7)
Below $\overline{K}N$ threshold

$\Sigma(1385)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda\pi$	(87.0 ± 1.5) %		208
$\Sigma\pi$	(11.7 ± 1.5) %		129
$\Lambda\gamma$	$(1.25^{+0.13}_{-0.12})$ %		241
$\Sigma^+\gamma$	$(7.0 \pm 1.7) \times 10^{-3}$		180
$\Sigma^-\gamma$	$< 2.4 \times 10^{-4}$	90%	173

$\Sigma(1660)$ $1/2^+$

$I(J^P) = 1(\frac{1}{2}^+)$

Mass $m = 1630$ to 1690 (≈ 1660) MeV
Full width $\Gamma = 40$ to 200 (≈ 100) MeV

$\Sigma(1660)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	10–30 %	405

See Particle Listings for 2 decay modes that have been seen / not seen.

$\Sigma(1670)$ $3/2^-$, $\Sigma(1750)$ $1/2^-$, $\Sigma(1775)$ $5/2^-$, $\Sigma(1915)$ $5/2^+$, $\Sigma(1940)$ $3/2^-$, $\Sigma(2030)$ $7/2^+$, $\Sigma(2250)$

The Σ resonances listed above are omitted from this Booklet but not from the Summary Table in the full *Review*.

Ξ BARYONS
$(S=-2, I=1/2)$

$\Xi^0 = uss, \quad \Xi^- = dss$

Ξ^0

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

P is not yet measured; + is the quark model prediction.

Mass $m = 1314.86 \pm 0.20$ MeV
$m_{\Xi^-} - m_{\Xi^0} = 6.85 \pm 0.21$ MeV
Mean life $\tau = (2.90 \pm 0.09) \times 10^{-10}$ s
$c\tau = 8.71$ cm
Magnetic moment $\mu = -1.250 \pm 0.014\ \mu_N$

Decay parameters

$\Lambda\pi^0$	$\alpha = -0.406 \pm 0.013$
"	$\phi = (21 \pm 12)^\circ$
"	$\gamma = 0.85$ [n]
"	$\Delta = (218^{+12}_{-19})^\circ$ [n]
$\Lambda\gamma$	$\alpha = -0.70 \pm 0.07$
$\Lambda e^+ e^-$	$\alpha = -0.8 \pm 0.2$
$\Sigma^0\gamma$	$\alpha = -0.69 \pm 0.06$
$\Sigma^+ e^- \overline{\nu}_e$	$g_1(0)/f_1(0) = 1.22 \pm 0.05$
$\Sigma^+ e^- \overline{\nu}_e$	$f_2(0)/f_1(0) = 2.0 \pm 0.9$

Ξ^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda\pi^0$		(99.524 ± 0.012) %		135
$\Lambda\gamma$		$(1.17 \pm 0.07) \times 10^{-3}$		184
$\Lambda e^+ e^-$		$(7.6 \pm 0.6) \times 10^{-6}$		184
$\Sigma^0\gamma$		$(3.33 \pm 0.10) \times 10^{-3}$		117
$\Sigma^+ e^- \overline{\nu}_e$		$(2.52 \pm 0.08) \times 10^{-4}$		120
$\Sigma^+ \mu^- \overline{\nu}_\mu$		$(2.33 \pm 0.35) \times 10^{-6}$		64
$\Delta S = \Delta Q$ (*SQ*) violating modes or $\Delta S = 2$ forbidden (*S2*) modes				
$\Sigma^- e^+ \nu_e$	*SQ*	$< 9 \times 10^{-4}$	90%	112
$\Sigma^- \mu^+ \nu_\mu$	*SQ*	$< 9 \times 10^{-4}$	90%	49
$p\pi^-$	*S2*	$< 8 \times 10^{-6}$	90%	299
$p e^- \overline{\nu}_e$	*S2*	$< 1.3 \times 10^{-3}$		323
$p \mu^- \overline{\nu}_\mu$	*S2*	$< 1.3 \times 10^{-3}$		309

Ξ^-

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

P is not yet measured; + is the quark model prediction.

Mass $m = 1321.71 \pm 0.07$ MeV
$(m_{\Xi^-} - m_{\overline{\Xi}^+}) / m_{\Xi^-} = (-3 \pm 9) \times 10^{-5}$
Mean life $\tau = (1.639 \pm 0.015) \times 10^{-10}$ s
$c\tau = 4.91$ cm
$(\tau_{\Xi^-} - \tau_{\overline{\Xi}^+}) / \tau_{\Xi^-} = -0.01 \pm 0.07$
Magnetic moment $\mu = -0.6507 \pm 0.0025\ \mu_N$
$(\mu_{\Xi^-} + \mu_{\overline{\Xi}^+}) / \left|\mu_{\Xi^-}\right| = +0.01 \pm 0.05$

Decay parameters

$\Lambda\pi^-$ $\alpha = -0.458 \pm 0.012$ (S = 1.8)

$[\alpha(\Xi^-)\alpha_-(\Lambda) - \alpha(\overline{\Xi}^+)\alpha_+(\overline{\Lambda})]$ / [sum] = $(0 \pm 7) \times 10^{-4}$

" $\phi = (-2.1 \pm 0.8)°$

" $\gamma = 0.89$ [n]

" $\Delta = (175.9 \pm 1.5)°$ [n]

$\Lambda e^- \overline{\nu}_e$ $g_A/g_V = -0.25 \pm 0.05$ [i]

Ξ^- DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda\pi^-$		(99.887 ± 0.035) %		140
$\Sigma^-\gamma$		$(1.27 \pm0.23) \times 10^{-4}$		118
$\Lambda e^-\overline{\nu}_e$		$(5.63 \pm0.31) \times 10^{-4}$		190
$\Lambda\mu^-\overline{\nu}_\mu$		$(3.5 {}^{+3.5}_{-2.2}) \times 10^{-4}$		163
$\Sigma^0 e^-\overline{\nu}_e$		$(8.7 \pm1.7) \times 10^{-5}$		123
$\Sigma^0 \mu^-\overline{\nu}_\mu$		$< 8 \times 10^{-4}$	90%	70
$\Xi^0 e^-\overline{\nu}_e$		$< 2.3 \times 10^{-3}$	90%	7
$\Delta S = 2$ forbidden ($S2$) modes				
$n\pi^-$	$S2$	$< 1.9 \times 10^{-5}$	90%	304
$ne^-\overline{\nu}_e$	$S2$	$< 3.2 \times 10^{-3}$	90%	327
$n\mu^-\overline{\nu}_\mu$	$S2$	< 1.5 %	90%	314
$p\pi^-\pi^-$	$S2$	$< 4 \times 10^{-4}$	90%	223
$p\pi^- e^-\overline{\nu}_e$	$S2$	$< 4 \times 10^{-4}$	90%	305
$p\pi^- \mu^-\overline{\nu}_\mu$	$S2$	$< 4 \times 10^{-4}$	90%	251
$p\mu^-\mu^-$	L	$< 4 \times 10^{-8}$	90%	272

$\Xi(1530)$ $3/2^+$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$

$\Xi(1530)^0$ mass $m = 1531.80 \pm 0.32$ MeV (S = 1.3)

$\Xi(1530)^-$ mass $m = 1535.0 \pm 0.6$ MeV

$\Xi(1530)^0$ full width $\Gamma = 9.1 \pm 0.5$ MeV

$\Xi(1530)^-$ full width $\Gamma = 9.9^{+1.7}_{-1.9}$ MeV

$\Xi(1530)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Xi\pi$	100 %		158
$\Xi\gamma$	<4 %	90%	202

$\Xi(1690)$, $\Xi(1820)$ $3/2^-$, $\Xi(1950)$, $\Xi(2030)$

The Ξ resonances listed above are omitted from this Booklet but not from the Summary Table in the full *Review*.

Ω BARYONS
$(S=-3, I=0)$

$\Omega^- = sss$

Ω^-

$I(J^P) = 0(\frac{3}{2}^+)$

$J^P = \frac{3}{2}^+$ is the quark-model prediction; and $J = 3/2$ is fairly well established.

Mass $m = 1672.45 \pm 0.29$ MeV
$(m_{\Omega^-} - m_{\overline{\Omega}^+}) \ / \ m_{\Omega^-} = (-1 \pm 8) \times 10^{-5}$
Mean life $\tau = (0.821 \pm 0.011) \times 10^{-10}$ s
$c\tau = 2.461$ cm
$(\tau_{\Omega^-} - \tau_{\overline{\Omega}^+}) \ / \ \tau_{\Omega^-} = 0.00 \pm 0.05$
Magnetic moment $\mu = -2.02 \pm 0.05 \ \mu_N$

Decay parameters

ΛK^-	$\alpha = 0.0180 \pm 0.0024$
ΛK^-, $\overline{\Lambda} K^+$	$(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha}) = -0.02 \pm 0.13$
$\Xi^0 \pi^-$	$\alpha = 0.09 \pm 0.14$
$\Xi^- \pi^0$	$\alpha = 0.05 \pm 0.21$

Ω^- DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
ΛK^-		(67.8 ± 0.7) %		211
$\Xi^0 \pi^-$		(23.6 ± 0.7) %		294
$\Xi^- \pi^0$		(8.6 ± 0.4) %		289
$\Xi^- \pi^+ \pi^-$		$(3.7^{+0.7}_{-0.6}) \times 10^{-4}$		189
$\Xi(1530)^0 \pi^-$		$< 7 \times 10^{-5}$	90%	17
$\Xi^0 e^- \overline{\nu}_e$		$(5.6 \pm 2.8) \times 10^{-3}$		319
$\Xi^- \gamma$		$< 4.6 \times 10^{-4}$	90%	314
$\Delta S = 2$ forbidden ($S2$) modes				
$\Lambda \pi^-$	$S2$	$< 2.9 \times 10^{-6}$	90%	449

$\Omega(2250)^-$

$I(J^P) = 0(?^?)$

Mass $m = 2252 \pm 9$ MeV
Full width $\Gamma = 55 \pm 18$ MeV

CHARMED BARYONS
$(C=+1)$

$\Lambda_c^+ = u\,d\,c,\quad \Sigma_c^{++} = u\,u\,c,\quad \Sigma_c^+ = u\,d\,c,\quad \Sigma_c^0 = d\,d\,c,$
$\Xi_c^+ = u\,s\,c,\quad \Xi_c^0 = d\,s\,c,\quad \Omega_c^0 = s\,s\,c$

Λ_c^+

$I(J^P) = 0(\frac{1}{2}^+)$

Mass $m = 2286.46 \pm 0.14$ MeV
Mean life $\tau = (200 \pm 6) \times 10^{-15}$ s (S = 1.6)
$c\tau = 59.9\ \mu$m

Decay asymmetry parameters

$\Lambda\pi^+$ $\alpha = -0.91 \pm 0.15$
$\Sigma^+\pi^0$ $\alpha = -0.45 \pm 0.32$
$\Lambda\ell^+\nu_\ell$ $\alpha = -0.86 \pm 0.04$
$(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Lambda_c^+ \to \Lambda\pi^+$, $\overline{\Lambda}_c^- \to \overline{\Lambda}\pi^- = -0.07 \pm 0.31$
$(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Lambda_c^+ \to \Lambda e^+\nu_e$, $\overline{\Lambda}_c^- \to \overline{\Lambda} e^-\overline{\nu}_e = 0.00 \pm 0.04$

Branching fractions marked with a footnote, e.g. [a], have been corrected for decay modes not observed in the experiments. For example, the submode fraction $\Lambda_c^+ \to p\overline{K}^*(892)^0$ seen in $\Lambda_c^+ \to pK^-\pi^+$ has been multiplied up to include $\overline{K}^*(892)^0 \to \overline{K}^0\pi^0$ decays.

Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Hadronic modes with a p or n: $S = -1$ final states				
pK_S^0		(1.58 ± 0.08) %	S=1.1	873
$pK^-\pi^+$		(6.23 ± 0.33) %	S=1.4	823
$p\overline{K}^*(892)^0$	[r]	(1.94 ± 0.27) %		685
$\Delta(1232)^{++}K^-$		(1.07 ± 0.25) %		710
$\Lambda(1520)\pi^+$	[r]	(2.2 ± 0.5) %		627
$pK^-\pi^+$ nonresonant		(3.4 ± 0.4) %		823
$pK_S^0\pi^0$		(1.96 ± 0.13) %	S=1.1	823
$nK_S^0\pi^+$		(1.82 ± 0.25) %		821
$p\overline{K}^0\eta$		(1.6 ± 0.4) %		568
$pK_S^0\pi^+\pi^-$		(1.59 ± 0.12) %	S=1.2	754
$pK^-\pi^+\pi^0$		(4.42 ± 0.31) %	S=1.5	759
$pK^*(892)^-\pi^+$	[r]	(1.4 ± 0.5) %		580
$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(4.5 ± 0.8) %		759
$pK^-2\pi^+\pi^-$		$(1.4 \pm 0.9) \times 10^{-3}$		671
$pK^-\pi^+2\pi^0$		$(10 \pm 5) \times 10^{-3}$		678
Hadronic modes with a p: $S = 0$ final states				
$p\pi^0$		$< 2.7 \times 10^{-4}$	CL=90%	945
$p\eta$		$(1.24 \pm 0.30) \times 10^{-3}$		856
$p\pi^+\pi^-$		$(4.2 \pm 0.4) \times 10^{-3}$		927
$pf_0(980)$	[r]	$(3.4 \pm 2.3) \times 10^{-3}$		614
$p2\pi^+2\pi^-$		$(2.2 \pm 1.4) \times 10^{-3}$		852
pK^+K^-		$(10 \pm 4) \times 10^{-4}$		616

$p\phi$	[r]	$(1.06\pm 0.14)\times 10^{-3}$		590
pK^+K^- non-ϕ		$(5.2\pm 1.2)\times 10^{-4}$		616
$p\phi\pi^0$		$(10\pm 4)\times 10^{-5}$		460
$pK^+K^-\pi^0$ nonresonant		$<6.3\times 10^{-5}$	CL=90%	494

Hadronic modes with a hyperon: $S=-1$ final states

$\Lambda\pi^+$		(1.29 ± 0.07) %	S=1.2	864
$\Lambda\pi^+\pi^0$		(7.0 ± 0.4) %	S=1.1	844
$\Lambda\rho^+$		<6 %	CL=95%	636
$\Lambda\pi^-2\pi^+$		(3.61 ± 0.29) %	S=1.5	807
$\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+}\to\Lambda\pi^+$		(1.0 ± 0.5) %		688
$\Sigma(1385)^-2\pi^+$, $\Sigma^{*-}\to\Lambda\pi^-$		$(7.6\pm 1.4)\times 10^{-3}$		688
$\Lambda\pi^+\rho^0$		(1.4 ± 0.6) %		524
$\Sigma(1385)^+\rho^0$, $\Sigma^{*+}\to\Lambda\pi^+$		$(5\pm 4)\times 10^{-3}$		363
$\Lambda\pi^-2\pi^+$ nonresonant		<1.1 %	CL=90%	807
$\Lambda\pi^-\pi^0 2\pi^+$ total		(2.2 ± 0.8) %		757
$\Lambda\pi^+\eta$	[r]	(2.2 ± 0.5) %		691
$\Sigma(1385)^+\eta$	[r]	(1.06 ± 0.32) %		570
$\Lambda\pi^+\omega$	[r]	(1.5 ± 0.5) %		517
$\Lambda\pi^-\pi^0 2\pi^+$, no η or ω		$<8\times 10^{-3}$	CL=90%	757
$\Lambda K^+\overline{K}^0$		$(5.6\pm 1.1)\times 10^{-3}$	S=1.9	443
$\Xi(1690)^0K^+$, $\Xi^{*0}\to\Lambda\overline{K}^0$		$(1.6\pm 0.5)\times 10^{-3}$		286
$\Sigma^0\pi^+$		(1.28 ± 0.07) %	S=1.1	825
$\Sigma^+\pi^0$		(1.24 ± 0.10) %		827
$\Sigma^+\eta$		$(6.9\pm 2.3)\times 10^{-3}$		713
$\Sigma^+\pi^+\pi^-$		(4.42 ± 0.28) %	S=1.2	804
$\Sigma^+\rho^0$		<1.7 %	CL=95%	575
$\Sigma^-2\pi^+$		(1.86 ± 0.18) %		799
$\Sigma^0\pi^+\pi^0$		(2.2 ± 0.8) %		803
$\Sigma^0\pi^-2\pi^+$		(1.10 ± 0.30) %		763
$\Sigma^+\pi^+\pi^-\pi^0$		—		767
$\Sigma^+\omega$	[r]	(1.69 ± 0.21) %		569
$\Sigma^-\pi^0 2\pi^+$		(2.1 ± 0.4) %		762
$\Sigma^+K^+K^-$		$(3.4\pm 0.4)\times 10^{-3}$	S=1.1	349
$\Sigma^+\phi$	[r]	$(3.8\pm 0.6)\times 10^{-3}$	S=1.1	295
$\Xi(1690)^0K^+$, $\Xi^{*0}\to\Sigma^+K^-$		$(10.0\pm 2.5)\times 10^{-4}$		286
$\Sigma^+K^+K^-$ nonresonant		$<8\times 10^{-4}$	CL=90%	349
Ξ^0K^+		$(4.9\pm 1.2)\times 10^{-3}$		653
$\Xi^-K^+\pi^+$		$(6.2\pm 0.6)\times 10^{-3}$	S=1.1	565
$\Xi(1530)^0K^+$, $\Xi^0\to\Xi^-\pi^+$		$(3.3\pm 1.2)\times 10^{-3}$		473

Hadronic modes with a hyperon: $S=0$ final states

ΛK^+		$(6.0\pm 1.2)\times 10^{-4}$		781
$\Lambda K^+\pi^+\pi^-$		$<5\times 10^{-4}$	CL=90%	637
Σ^0K^+		$(5.1\pm 0.8)\times 10^{-4}$		735
$\Sigma^0K^+\pi^+\pi^-$		$<2.6\times 10^{-4}$	CL=90%	574
$\Sigma^+K^+\pi^-$		$(2.1\pm 0.6)\times 10^{-3}$		670
$\Sigma^+K^*(892)^0$	[r]	$(3.4\pm 1.0)\times 10^{-3}$		469
$\Sigma^-K^+\pi^+$		$<1.2\times 10^{-3}$	CL=90%	664

Doubly Cabibbo-suppressed modes

$pK^+\pi^-$		$(1.46\pm 0.23)\times 10^{-4}$		823

Semileptonic modes

$\Lambda e^+\nu_e$		(3.6 ± 0.4) %		871
$\Lambda\mu^+\nu_\mu$		(3.5 ± 0.5) %		867

Inclusive modes

e^+ anything		(4.5 ± 1.7) %			–
pe^+ anything		(1.8 ± 0.9) %			–
p anything		(50 ± 16) %			–
p anything (no Λ)		(12 ± 19) %			–
n anything		(50 ± 16) %			–
n anything (no Λ)		(29 ± 17) %			–
Λ anything		(35 ± 11) %		S=1.4	–
$\Sigma^{\pm}$ anything	[s]	(10 ± 5) %			–
3prongs		(24 ± 8) %			–

$\Delta C = 1$ weak neutral current (*C1*) modes, or Lepton Family number (*LF*), or Lepton number (*L*), or Baryon number (*B*) violating modes

pe^+e^-	C1	< 5.5	$\times 10^{-6}$	CL=90%	951
$p\mu^+\mu^-$	C1	< 4.4	$\times 10^{-5}$	CL=90%	937
$pe^+\mu^-$	LF	< 9.9	$\times 10^{-6}$	CL=90%	947
$pe^-\mu^+$	LF	< 1.9	$\times 10^{-5}$	CL=90%	947
$\overline{p}2e^+$	L,B	< 2.7	$\times 10^{-6}$	CL=90%	951
$\overline{p}2\mu^+$	L,B	< 9.4	$\times 10^{-6}$	CL=90%	937
$\overline{p}e^+\mu^+$	L,B	< 1.6	$\times 10^{-5}$	CL=90%	947
$\Sigma^-\mu^+\mu^+$	L	< 7.0	$\times 10^{-4}$	CL=90%	812

See Particle Listings for 1 decay modes that have been seen / not seen.

$\Lambda_c(2595)^+$

$I(J^P) = 0(\frac{1}{2}^-)$

The spin-parity follows from the fact that $\Sigma_c(2455)\pi$ decays, with little available phase space, are dominant. This assumes that $J^P = 1/2^+$ for the $\Sigma_c(2455)$.

Mass $m = 2592.25 \pm 0.28$ MeV
$m - m_{\Lambda_c^+} = 305.79 \pm 0.24$ MeV
Full width $\Gamma = 2.6 \pm 0.6$ MeV

$\Lambda_c^+\pi\pi$ and its submode $\Sigma_c(2455)\pi$ — the latter just barely — are the only strong decays allowed to an excited Λ_c^+ having this mass; and the submode seems to dominate.

$\Lambda_c(2595)^+$ DECAY MODES		Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_c^+\pi^+\pi^-$	[t]	—	117
$\Sigma_c(2455)^{++}\pi^-$		24 ± 7 %	†
$\Sigma_c(2455)^0\pi^+$		24 ± 7 %	†
$\Lambda_c^+\pi^+\pi^-$ 3-body		18 ± 10 %	117

See Particle Listings for 2 decay modes that have been seen / not seen.

$\Lambda_c(2625)^+$

$I(J^P) = 0(\frac{3}{2}^-)$

J^P has not been measured; $\frac{3}{2}^-$ is the quark-model prediction.

Mass $m = 2628.11 \pm 0.19$ MeV (S = 1.1)
$m - m_{\Lambda_c^+} = 341.65 \pm 0.13$ MeV (S = 1.1)
Full width $\Gamma < 0.97$ MeV, CL = 90%

$\Lambda_c^+\pi\pi$ and its submode $\Sigma(2455)\pi$ are the only strong decays allowed to an excited Λ_c^+ having this mass.

$\Lambda_c(2625)^+$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$\Lambda_c^+\pi^+\pi^-$	$\approx 67\%$		184
$\Sigma_c(2455)^{++}\pi^-$	<5	90%	102
$\Sigma_c(2455)^0\pi^+$	<5	90%	102
$\Lambda_c^+\pi^+\pi^-$ 3-body	large		184

See Particle Listings for 2 decay modes that have been seen / not seen.

$\Lambda_c(2860)^+$

$I(J^P) = 0(\frac{3}{2}^+)$

Mass $m = 2856.1^{+2.3}_{-6.0}$ MeV
Full width $\Gamma = 68^{+12}_{-22}$ MeV

$\Lambda_c(2880)^+$

$I(J^P) = 0(\frac{5}{2}^+)$

Mass $m = 2881.63 \pm 0.24$ MeV
$m - m_{\Lambda_c^+} = 595.17 \pm 0.28$ MeV
Full width $\Gamma = 5.6^{+0.8}_{-0.6}$ MeV

$\Lambda_c(2940)^+$

$I(J^P) = 0(\frac{3}{2}^-)$

$J^P = 3/2^-$ is favored, but is not certain

Mass $m = 2939.6^{+1.3}_{-1.5}$ MeV
Full width $\Gamma = 20^{+6}_{-5}$ MeV

$\Sigma_c(2455)$

$I(J^P) = 1(\frac{1}{2}^+)$

$\Sigma_c(2455)^{++}$ mass $m = 2453.97 \pm 0.14$ MeV
$\Sigma_c(2455)^{+}$ mass $m = 2452.9 \pm 0.4$ MeV
$\Sigma_c(2455)^{0}$ mass $m = 2453.75 \pm 0.14$ MeV
$m_{\Sigma_c^{++}} - m_{\Lambda_c^+} = 167.510 \pm 0.017$ MeV
$m_{\Sigma_c^{+}} - m_{\Lambda_c^+} = 166.4 \pm 0.4$ MeV
$m_{\Sigma_c^{0}} - m_{\Lambda_c^+} = 167.290 \pm 0.017$ MeV
$m_{\Sigma_c^{++}} - m_{\Sigma_c^0} = 0.220 \pm 0.013$ MeV
$m_{\Sigma_c^{+}} - m_{\Sigma_c^0} = -0.9 \pm 0.4$ MeV
$\Sigma_c(2455)^{++}$ full width $\Gamma = 1.89^{+0.09}_{-0.18}$ MeV (S = 1.1)
$\Sigma_c(2455)^{+}$ full width $\Gamma < 4.6$ MeV, CL = 90%
$\Sigma_c(2455)^{0}$ full width $\Gamma = 1.83^{+0.11}_{-0.19}$ MeV (S = 1.2)

$\Lambda_c^+\pi$ is the only strong decay allowed to a Σ_c having this mass.

$\Sigma_c(2455)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_c^+\pi$	$\approx 100\ \%$	94

$\Sigma_c(2520)$

$I(J^P) = 1(\frac{3}{2}^+)$

J^P has not been measured; $\frac{3}{2}^+$ is the quark-model prediction.

$\Sigma_c(2520)^{++}$ mass $m = 2518.41^{+0.21}_{-0.19}$ MeV (S = 1.1)
$\Sigma_c(2520)^{+}$ mass $m = 2517.5 \pm 2.3$ MeV
$\Sigma_c(2520)^{0}$ mass $m = 2518.48 \pm 0.20$ MeV (S = 1.1)
$m_{\Sigma_c(2520)^{++}} - m_{\Lambda_c^+} = 231.95^{+0.17}_{-0.12}$ MeV (S = 1.3)
$m_{\Sigma_c(2520)^{+}} - m_{\Lambda_c^+} = 231.0 \pm 2.3$ MeV
$m_{\Sigma_c(2520)^{0}} - m_{\Lambda_c^+} = 232.02^{+0.15}_{-0.14}$ MeV (S = 1.3)
$m_{\Sigma_c(2520)^{++}} - m_{\Sigma_c(2520)^{0}} = 0.01 \pm 0.15$ MeV
$\Sigma_c(2520)^{++}$ full width $\Gamma = 14.78^{+0.30}_{-0.40}$ MeV
$\Sigma_c(2520)^{+}$ full width $\Gamma < 17$ MeV, CL = 90%
$\Sigma_c(2520)^{0}$ full width $\Gamma = 15.3^{+0.4}_{-0.5}$ MeV

$\Lambda_c^+ \pi$ is the only strong decay allowed to a Σ_c having this mass.

Σ_c(2520) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_c^+ \pi$	$\approx$ 100 %	179

$\Sigma_c(2800)$

$I(J^P) = 1(?^?)$

$\Sigma_c(2800)^{++}$ mass $m = 2801^{+4}_{-6}$ MeV
$\Sigma_c(2800)^{+}$ mass $m = 2792^{+14}_{-\ 5}$ MeV
$\Sigma_c(2800)^{0}$ mass $m = 2806^{+5}_{-7}$ MeV (S = 1.3)
$m_{\Sigma_c(2800)^{++}} - m_{\Lambda_c^+} = 514^{+4}_{-6}$ MeV
$m_{\Sigma_c(2800)^{+}} - m_{\Lambda_c^+} = 505^{+14}_{-\ 5}$ MeV
$m_{\Sigma_c(2800)^{0}} - m_{\Lambda_c^+} = 519^{+5}_{-7}$ MeV (S = 1.3)
$\Sigma_c(2800)^{++}$ full width $\Gamma = 75^{+22}_{-17}$ MeV
$\Sigma_c(2800)^{+}$ full width $\Gamma = 62^{+60}_{-40}$ MeV
$\Sigma_c(2800)^{0}$ full width $\Gamma = 72^{+22}_{-15}$ MeV

Ξ_c^+

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

J^P has not been measured; $\frac{1}{2}^+$ is the quark-model prediction.

Mass $m = 2467.87 \pm 0.30$ MeV (S = 1.1)
Mean life $\tau = (442 \pm 26) \times 10^{-15}$ s (S = 1.3)
$c\tau = 132\ \mu$m

Branching fractions marked with a footnote, e.g. [a], have been corrected for decay modes not observed in the experiments. For example, the submode fraction $\Xi_c^+ \to \Sigma^+ \overline{K}^*(892)^0$ seen in $\Xi_c^+ \to \Sigma^+ K^- \pi^+$ has been multiplied up to include $\overline{K}^*(892)^0 \to \overline{K}^0 \pi^0$ decays.

Ξ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
No absolute branching fractions have been measured. **The following are branching *ratios* relative to $\Xi^- 2\pi^+$.**				
Cabibbo-favored ($S = -2$) decays — relative to $\Xi^- 2\pi^+$				
$p 2K_S^0$		0.087 ± 0.021		767
$\Lambda \overline{K}^0 \pi^+$		—		852
$\Sigma(1385)^+ \overline{K}^0$	[r]	1.0 ± 0.5		746
$\Lambda K^- 2\pi^+$		0.323 ± 0.033		787
$\Lambda \overline{K}^*(892)^0 \pi^+$	[r]	<0.16	90%	608
$\Sigma(1385)^+ K^- \pi^+$	[r]	<0.23	90%	678
$\Sigma^+ K^- \pi^+$		0.94 ± 0.10		811
$\Sigma^+ \overline{K}^*(892)^0$	[r]	0.81 ± 0.15		658
$\Sigma^0 K^- 2\pi^+$		0.27 ± 0.12		735
$\Xi^0 \pi^+$		0.55 ± 0.16		877
$\Xi^- 2\pi^+$		**DEFINED AS 1**		851
$\Xi(1530)^0 \pi^+$	[r]	<0.10	90%	750
$\Xi^0 \pi^+ \pi^0$		2.3 ± 0.7		856
$\Xi^0 \pi^- 2\pi^+$		1.7 ± 0.5		818
$\Xi^0 e^+ \nu_e$		$2.3 \, ^{+0.7}_{-0.8}$		884
$\Omega^- K^+ \pi^+$		0.07 ± 0.04		399
Cabibbo-suppressed decays — relative to $\Xi^- 2\pi^+$				
$p K^- \pi^+$		0.21 ± 0.04		944
$p \overline{K}^*(892)^0$	[r]	0.116 ± 0.030		828
$\Sigma^+ \pi^+ \pi^-$		0.48 ± 0.20		922
$\Sigma^- 2\pi^+$		0.18 ± 0.09		918
$\Sigma^+ K^+ K^-$		0.15 ± 0.06		579
$\Sigma^+ \phi$	[r]	<0.11	90%	549
$\Xi(1690)^0 K^+$, $\Xi^0 \to \Sigma^+ K^-$		<0.05	90%	501

Ξ_c^0

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

J^P has not been measured; $\frac{1}{2}^+$ is the quark-model prediction.

Mass $m = 2470.87^{+0.28}_{-0.31}$ MeV

$m_{\Xi_c^0} - m_{\Xi_c^+} = 3.00 \pm 0.24$ MeV

Mean life $\tau = (112^{+13}_{-10}) \times 10^{-15}$ s

$c\tau = 33.6$ μm

Decay asymmetry parameters

$\Xi^- \pi^+$ $\alpha = -0.6 \pm 0.4$

Branching fractions marked with a footnote, e.g. [*a*], have been corrected for decay modes not observed in the experiments. For example, the submode fraction $\Xi_c^0 \to p K^- \overline{K}^*(892)^0$ seen in $\Xi_c^0 \to p K^- K^- \pi^+$ has been multiplied up to include $\overline{K}^*(892)^0 \to \overline{K}^0 \pi^0$ decays.

Ξ_c^0 DECAY MODES		Fraction (Γ_i/Γ)	p (MeV/c)
No absolute branching fractions have been measured. The following are branching *ratios* relative to $\Xi^-\pi^+$.			
Cabibbo-favored (S = −2) decays — relative to $\Xi^-\pi^+$			
$pK^-K^-\pi^+$		0.34 ± 0.04	676
$pK^-\overline{K}^*(892)^0$	[r]	0.21 ± 0.05	413
$pK^-K^-\pi^+$ (no $\overline{K}^{*0}$)		0.21 ± 0.04	676
ΛK^0_S		0.210 ± 0.028	906
$\Lambda K^-\pi^+$		1.07 ± 0.14	856
$\Xi^-\pi^+$		**DEFINED AS 1**	875
$\Xi^-\pi^+\pi^+\pi^-$		3.3 ± 1.4	816
Ω^-K^+		0.297 ± 0.024	522
$\Xi^-e^+\nu_e$		3.1 ± 1.1	882
$\Xi^-\ell^+$ anything		1.0 ± 0.5	–
Cabibbo-suppressed decays — relative to $\Xi^-\pi^+$			
Ξ^-K^+		0.028 ± 0.006	790
ΛK^+K^- (no ϕ)		0.029 ± 0.007	648
$\Lambda\phi$	[r]	0.034 ± 0.007	621

See Particle Listings for 2 decay modes that have been seen / not seen.

$\Xi_c'^+$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

J^P has not been measured; $\frac{1}{2}^+$ is the quark-model prediction.

Mass $m = 2577.4 \pm 1.2$ MeV (S = 2.9)

$m_{\Xi_c'^+} - m_{\Xi_c^+} = 109.5 \pm 1.2$ MeV (S = 3.7)

$m_{\Xi_c'^+} - m_{\Xi_c'^0} = -1.4 \pm 1.3$ MeV (S = 2.5)

$\Xi_c'^0$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

J^P has not been measured; $\frac{1}{2}^+$ is the quark-model prediction.

Mass $m = 2578.8 \pm 0.5$ MeV (S = 1.2)

$m_{\Xi_c'^0} - m_{\Xi_c^0} = 108.0 \pm 0.4$ MeV (S = 1.2)

$\Xi_c(2645)$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$

J^P has not been measured; $\frac{3}{2}^+$ is the quark-model prediction.

$\Xi_c(2645)^+$ mass $m = 2645.53 \pm 0.31$ MeV

$\Xi_c(2645)^0$ mass $m = 2646.32 \pm 0.31$ MeV (S = 1.1)

$m_{\Xi_c(2645)^+} - m_{\Xi_c^0} = 174.66 \pm 0.09$ MeV

$m_{\Xi_c(2645)^0} - m_{\Xi_c^+} = 178.44 \pm 0.11$ MeV (S = 1.1)

$m_{\Xi_c(2645)^+} - m_{\Xi_c(2645)^0} = -0.79 \pm 0.27$ MeV

$\Xi_c(2645)^+$ full width $\Gamma = 2.14 \pm 0.19$ MeV (S = 1.1)

$\Xi_c(2645)^0$ full width $\Gamma = 2.35 \pm 0.22$ MeV

$\Xi_c(2790)$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$

J^P has not been measured; $\frac{1}{2}^-$ is the quark-model prediction.

$\Xi_c(2790)^+$ mass $= 2792.0 \pm 0.5$ MeV (S = 1.2)
$\Xi_c(2790)^0$ mass $= 2792.8 \pm 1.2$ MeV (S = 2.9)
$m_{\Xi_c(2790)^+} - m_{\Xi_c^0} = 321.1 \pm 0.4$ MeV (S = 1.2)
$m_{\Xi_c(2790)^0} - m_{\Xi_c^+} = 324.9 \pm 1.2$ MeV (S = 3.7)
$m_{\Xi_c(2790)^+} - m_{\Xi_c'^0} = 213.10 \pm 0.26$ MeV (S = 1.2)
$m_{\Xi_c(2790)^0} - m_{\Xi_c'^+} = 215.4 \pm 0.8$ MeV (S = 3.7)
$m_{\Xi_c(2790)^+} - m_{\Xi_c(2790)^0} = -0.9 \pm 1.3$ MeV (S = 2.5)
$\Xi_c(2790)^+$ width $= 8.9 \pm 1.0$ MeV
$\Xi_c(2790)^0$ width $= 10.0 \pm 1.1$ MeV

$\Xi_c(2815)$

$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$

J^P has not been measured; $\frac{3}{2}^-$ is the quark-model prediction.

$\Xi_c(2815)^+$ mass $m = 2816.67 \pm 0.31$ MeV (S = 1.1)
$\Xi_c(2815)^0$ mass $m = 2820.22 \pm 0.32$ MeV
$m_{\Xi_c(2815)^+} - m_{\Xi_c^+} = 348.80 \pm 0.10$ MeV
$m_{\Xi_c(2815)^0} - m_{\Xi_c^0} = 349.35 \pm 0.11$ MeV
$m_{\Xi_c(2815)^+} - m_{\Xi_c(2815)^0} = -3.55 \pm 0.28$ MeV
$\Xi_c(2815)^+$ full width $\Gamma = 2.43 \pm 0.26$ MeV
$\Xi_c(2815)^0$ full width $\Gamma = 2.54 \pm 0.25$ MeV

$\Xi_c(2970)$

$I(J^P) = \frac{1}{2}(?^?)$

$\Xi_c(2970)^+$ $m = 2969.4 \pm 0.8$ MeV (S = 1.1)
$\Xi_c(2970)^0$ $m = 2967.8 \pm 0.8$ MeV (S = 1.1)
$m_{\Xi_c(2970)^+} - m_{\Xi_c^0} = 498.5 \pm 0.8$ MeV (S = 1.1)
$m_{\Xi_c(2970)^0} - m_{\Xi_c^+} = 499.9^{+0.8}_{-0.7}$ MeV (S = 1.1)
$m_{\Xi_c(2970)^+} - m_{\Xi_c(2970)^0} = 1.6 \pm 1.1$ MeV (S = 1.1)
$\Xi_c(2970)^+$ width $\Gamma = 20.9^{+2.4}_{-3.5}$ MeV (S = 1.2)
$\Xi_c(2970)^0$ width $\Gamma = 28.1^{+3.4}_{-4.0}$ MeV (S = 1.5)

$\Xi_c(3055)$

$I(J^P) = ?(?^?)$

Mass $m = 3055.9 \pm 0.4$ MeV
Full width $\Gamma = 7.8 \pm 1.9$ MeV

$\Xi_c(3080)$

$I(J^P) = \frac{1}{2}(?^?)$

$\Xi_c(3080)^+$ $m = 3077.2 \pm 0.4$ MeV
$\Xi_c(3080)^0$ $m = 3079.9 \pm 1.4$ MeV (S = 1.3)
$\Xi_c(3080)^+$ width $\Gamma = 3.6 \pm 1.1$ MeV (S = 1.5)
$\Xi_c(3080)^0$ width $\Gamma = 5.6 \pm 2.2$ MeV

Ω_c^0

$I(J^P) = 0(\frac{1}{2}^+)$

J^P has not been measured; $\frac{1}{2}^+$ is the quark-model prediction.

Mass $m = 2695.2 \pm 1.7$ MeV (S = 1.3)
Mean life $\tau = (69 \pm 12) \times 10^{-15}$ s
$c\tau = 21$ μm

Ω_c^0 DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
No absolute branching fractions have been measured. The following are branching *ratios* relative to $\Omega^-\pi^+$.			
Cabibbo-favored ($S = -3$) decays — relative to $\Omega^-\pi^+$			
$\Omega^-\pi^+$	**DEFINED AS 1**		821
$\Omega^-\pi^+\pi^0$	1.80 ± 0.33		797
$\Omega^-\rho^+$	>1.3	90%	532
$\Omega^-\pi^-2\pi^+$	0.31 ± 0.05		753
$\Omega^-e^+\nu_e$	2.4 ± 1.2		829
$\Xi^0\overline{K}^0$	1.64 ± 0.29		950
$\Xi^0K^-\pi^+$	1.20 ± 0.18		901
$\Xi^0\overline{K}^{*0}$, $\overline{K}^{*0} \to K^-\pi^+$	0.68 ± 0.16		764
$\Xi^-\overline{K}^0\pi^+$	2.12 ± 0.28		895
$\Xi^-K^-2\pi^+$	0.63 ± 0.09		830
$\Xi(1530)^0K^-\pi^+$, $\Xi^{*0} \to \Xi^-\pi^+$	0.21 ± 0.06		757
$\Xi^-\overline{K}^{*0}\pi^+$	0.34 ± 0.11		653
$\Sigma^+K^-K^-\pi^+$	<0.32	90%	689
$\Lambda\overline{K}^0\overline{K}^0$	1.72 ± 0.35		837

$\Omega_c(2770)^0$

$I(J^P) = 0(\frac{3}{2}^+)$

J^P has not been measured; $\frac{3}{2}^+$ is the quark-model prediction.

Mass $m = 2765.9 \pm 2.0$ MeV (S = 1.2)
$m_{\Omega_c(2770)^0} - m_{\Omega_c^0} = 70.7^{+0.8}_{-0.9}$ MeV

The $\Omega_c(2770)^0$–Ω_c^0 mass difference is too small for any strong decay to occur.

$\Omega_c(2770)^0$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Omega_c^0\gamma$	presumably 100%	70

$\Omega_c(3000)^0$

$I(J^P) = ?(?^?)$

Mass $m = 3000.4 \pm 0.4$ MeV
Full width $\Gamma = 4.5 \pm 0.7$ MeV

$\Omega_c(3050)^0$

$I(J^P) = ?(?^?)$

Mass $m = 3050.2 \pm 0.33$ MeV
Full width $\Gamma < 1.2$ MeV, CL = 95%

$\Omega_c(3065)^0$

$I(J^P) = ?(?^?)$

Mass $m = 3065.6 \pm 0.4$ MeV
Full width $\Gamma = 3.5 \pm 0.4$ MeV

$\Omega_c(3090)^0$

$I(J^P) = ?(?^?)$

Mass $m = 3090.2 \pm 0.7$ MeV
Full width $\Gamma = 8.7 \pm 1.3$ MeV

$\Omega_c(3120)^0$

$I(J^P) = ?(?^?)$

Mass $m = 3119.1 \pm 1.0$ MeV
Full width $\Gamma < 2.6$ MeV, CL = 95%

DOUBLY CHARMED BARYONS ($C = +2$)

$\Xi_{cc}^{++} = u\,c\,c$, $\Xi_{cc}^{+} = d\,c\,c$, $\Omega_{cc}^{+} = s\,c\,c$

Ξ_{cc}^{++}

$I(J^P) = ?(?^?)$

Mass $m = 3621.4 \pm 0.8$ MeV

BOTTOM BARYONS ($B = -1$)

$\Lambda_b^0 = u\,d\,b$, $\Xi_b^0 = u\,s\,b$, $\Xi_b^- = d\,s\,b$, $\Omega_b^- = s\,s\,b$

Λ_b^0

$I(J^P) = 0(\frac{1}{2}^+)$

$I(J^P)$ not yet measured; $0(\frac{1}{2}^+)$ is the quark model prediction.

Mass $m = 5619.60 \pm 0.17$ MeV
$m_{\Lambda_b^0} - m_{B^0} = 339.2 \pm 1.4$ MeV
$m_{\Lambda_b^0} - m_{B^+} = 339.72 \pm 0.28$ MeV
Mean life $\tau = (1.470 \pm 0.010) \times 10^{-12}$ s
$c\tau = 440.7$ μm
$A_{CP}(\Lambda_b \to p\pi^-) = 0.06 \pm 0.08$
$A_{CP}(\Lambda_b \to pK^-) = -0.10 \pm 0.09$
$A_{CP}(\Lambda_b \to p\overline{K}^0\pi^-) = 0.22 \pm 0.13$
$\Delta A_{CP}(J/\psi\, p\pi^- / K^-) \equiv A_{CP}(J/\psi\, p\pi^-) - A_{CP}(J/\psi\, pK^-) = (5.7 \pm 2.7) \times 10^{-2}$
$A_{CP}(\Lambda_b \to \Lambda K^+\pi^-) = -0.53 \pm 0.25$
$A_{CP}(\Lambda_b \to \Lambda K^+K^-) = -0.28 \pm 0.12$
$\Delta A_{CP}(\Lambda_b^0 \to pK^-\mu^+\mu^-) \equiv A_{CP}(pK^-\mu^+\mu^-) - A_{CP}(pK^-J/\psi) = (-4 \pm 5) \times 10^{-2}$

α decay parameter for $\Lambda_b \to J/\psi \Lambda = 0.18 \pm 0.13$
$A^{\ell}_{FB}(\mu\mu)$ in $\Lambda_b \to \Lambda \mu^+ \mu^- = -0.05 \pm 0.09$
$A^{h}_{FB}(p\pi)$ in $\Lambda_b \to \Lambda(p\pi)\mu^+ \mu^- = -0.29 \pm 0.08$
$f_L(\mu\mu)$ longitudinal polarization fraction in $\Lambda_b \to \Lambda \mu^+ \mu^- = 0.61^{+0.11}_{-0.14}$

The branching fractions B(b-baryon $\to \Lambda \ell^- \overline{\nu}_\ell$ anything) and B($\Lambda_b^0 \to \Lambda_c^+ \ell^- \overline{\nu}_\ell$ anything) are not pure measurements because the underlying measured products of these with B($b \to b$-baryon) were used to determine B($b \to b$-baryon), as described in the note "Production and Decay of b-Flavored Hadrons."

For inclusive branching fractions, *e.g.*, $\Lambda_b \to \overline{\Lambda}_c$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

Λ_b^0 DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$J/\psi(1S)\Lambda \times$ B($b \to \Lambda_b^0$)		$(5.8 \pm 0.8) \times 10^{-5}$		1740
$p D^0 \pi^-$		$(6.3 \pm 0.7) \times 10^{-4}$		2370
$p D^0 K^-$		$(4.6 \pm 0.8) \times 10^{-5}$		2269
$p J/\psi \pi^-$		$(2.6 {}^{+0.5}_{-0.4}) \times 10^{-5}$		1755
$p \pi^- J/\psi$, $J/\psi \to \mu^+ \mu^-$		$(1.6 \pm 0.8) \times 10^{-6}$		–
$p J/\psi K^-$		$(3.2 {}^{+0.6}_{-0.5}) \times 10^{-4}$		1589
$P_c(4380)^+ K^-$, $P_c \to p J/\psi$	[u]	$(2.7 \pm 1.4) \times 10^{-5}$		–
$P_c(4450)^+ K^-$, $P_c \to p J/\psi$	[u]	$(1.3 \pm 0.4) \times 10^{-5}$		–
$\chi_{c1}(1P) p K^-$		$(7.6 {}^{+1.5}_{-1.3}) \times 10^{-5}$		1242
$\chi_{c2}(1P) p K^-$		$(7.9 {}^{+1.6}_{-1.4}) \times 10^{-5}$		1198
$p J/\psi(1S) \pi^+ \pi^- K^-$		$(6.6 {}^{+1.3}_{-1.1}) \times 10^{-5}$		1410
$p \psi(2S) K^-$		$(6.6 {}^{+1.2}_{-1.0}) \times 10^{-5}$		1063
$p \overline{K}^0 \pi^-$		$(1.3 \pm 0.4) \times 10^{-5}$		2693
$p K^0 K^-$		$< 3.5 \times 10^{-6}$	CL=90%	2639
$\Lambda_c^+ \pi^-$		$(4.9 \pm 0.4) \times 10^{-3}$	S=1.2	2342
$\Lambda_c^+ K^-$		$(3.59 \pm 0.30) \times 10^{-4}$	S=1.2	2314
$\Lambda_c^+ D^-$		$(4.6 \pm 0.6) \times 10^{-4}$		1886
$\Lambda_c^+ D_s^-$		(1.10 ± 0.10) %		1833
$\Lambda_c^+ \pi^+ \pi^- \pi^-$		$(7.7 \pm 1.1) \times 10^{-3}$	S=1.1	2323
$\Lambda_c(2595)^+ \pi^-$, $\Lambda_c(2595)^+ \to \Lambda_c^+ \pi^+ \pi^-$		$(3.4 \pm 1.5) \times 10^{-4}$		2210
$\Lambda_c(2625)^+ \pi^-$, $\Lambda_c(2625)^+ \to \Lambda_c^+ \pi^+ \pi^-$		$(3.3 \pm 1.3) \times 10^{-4}$		2193
$\Sigma_c(2455)^0 \pi^+ \pi^-$, $\Sigma_c^0 \to \Lambda_c^+ \pi^-$		$(5.7 \pm 2.2) \times 10^{-4}$		2265
$\Sigma_c(2455)^{++} \pi^- \pi^-$, $\Sigma_c^{++} \to \Lambda_c^+ \pi^+$		$(3.2 \pm 1.6) \times 10^{-4}$		2265
$\Lambda_c^+ \ell^- \overline{\nu}_\ell$ anything	[v]	(10.3 ± 2.1) %		–
$\Lambda_c^+ \ell^- \overline{\nu}_\ell$		$(6.2 {}^{+1.4}_{-1.3})$ %		2345
$\Lambda_c^+ \pi^+ \pi^- \ell^- \overline{\nu}_\ell$		(5.6 ± 3.1) %		2335
$\Lambda_c(2595)^+ \ell^- \overline{\nu}_\ell$		$(7.9 {}^{+4.0}_{-3.5}) \times 10^{-3}$		2212
$\Lambda_c(2625)^+ \ell^- \overline{\nu}_\ell$		$(1.3 {}^{+0.6}_{-0.5})$ %		2195

$p h^-$	[x] $< 2.3 \times 10^{-5}$	CL=90%	2730
$p\pi^-$	$(4.2 \pm 0.8) \times 10^{-6}$		2730
pK^-	$(5.1 \pm 0.9) \times 10^{-6}$		2709
pD_s^-	$< 4.8 \times 10^{-4}$	CL=90%	2364
$p\mu^-\overline{\nu}_\mu$	$(4.1 \pm 1.0) \times 10^{-4}$		2730
$\Lambda\mu^+\mu^-$	$(1.08 \pm 0.28) \times 10^{-6}$		2695
$p\pi^-\mu^+\mu^-$	$(6.9 \pm 2.5) \times 10^{-8}$		2720
$\Lambda\gamma$	$< 1.3 \times 10^{-3}$	CL=90%	2699
$\Lambda^0\eta$	$(9 \ {}^{+7}_{-5}) \times 10^{-6}$		–
$\Lambda^0\eta'(958)$	$< 3.1 \times 10^{-6}$	CL=90%	–
$\Lambda\pi^+\pi^-$	$(4.6 \pm 1.9) \times 10^{-6}$		2692
$\Lambda K^+\pi^-$	$(5.7 \pm 1.2) \times 10^{-6}$		2660
ΛK^+K^-	$(1.61 \pm 0.23) \times 10^{-5}$		2605
$\Lambda^0\phi$	$(9.2 \pm 2.5) \times 10^{-6}$		–

See Particle Listings for 1 decay modes that have been seen / not seen.

$\Lambda_b(5912)^0$

$J^P = \frac{1}{2}^-$

Mass $m = 5912.20 \pm 0.21$ MeV
Full width $\Gamma < 0.66$ MeV, CL = 90%

$\Lambda_b(5920)^0$

$J^P = \frac{3}{2}^-$

Mass $m = 5919.92 \pm 0.19$ MeV (S = 1.1)
Full width $\Gamma < 0.63$ MeV, CL = 90%

Σ_b

$I(J^P) = 1(\frac{1}{2}^+)$
I, J, P need confirmation.

Mass $m(\Sigma_b^+) = 5811.3 \pm 1.9$ MeV
Mass $m(\Sigma_b^-) = 5815.5 \pm 1.8$ MeV
$m_{\Sigma_b^+} - m_{\Sigma_b^-} = -4.2 \pm 1.1$ MeV
$\Gamma(\Sigma_b^+) = 9.7^{+4.0}_{-3.0}$ MeV
$\Gamma(\Sigma_b^-) = 4.9^{+3.3}_{-2.4}$ MeV

Σ_b DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_b^0\pi$	dominant	134

Σ_b^*

$I(J^P) = 1(\frac{3}{2}^+)$
I, J, P need confirmation.

Mass $m(\Sigma_b^{*+}) = 5832.1 \pm 1.9$ MeV
Mass $m(\Sigma_b^{*-}) = 5835.1 \pm 1.9$ MeV
$m_{\Sigma_b^{*+}} - m_{\Sigma_b^{*-}} = -3.0^{+1.0}_{-0.9}$ MeV
$\Gamma(\Sigma_b^{*+}) = 11.5 \pm 2.8$ MeV
$\Gamma(\Sigma_b^{*-}) = 7.5 \pm 2.3$ MeV
$m_{\Sigma_b^*} - m_{\Sigma_b} = 21.2 \pm 2.0$ MeV

Σ_b^* DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda_b^0 \pi$	dominant	161

Ξ_b^0, Ξ_b^-

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$
I, J, P need confirmation.

$m(\Xi_b^-) = 5797.0 \pm 0.9$ MeV (S = 1.8)
$m(\Xi_b^0) = 5791.9 \pm 0.5$ MeV
$m_{\Xi_b^-} - m_{\Lambda_b^0} = 177.5 \pm 0.5$ MeV (S = 1.6)
$m_{\Xi_b^0} - m_{\Lambda_b^0} = 172.5 \pm 0.4$ MeV
$m_{\Xi_b^-} - m_{\Xi_b^0} = 5.9 \pm 0.6$ MeV
Mean life $\tau_{\Xi_b^-} = (1.571 \pm 0.040) \times 10^{-12}$ s
Mean life $\tau_{\Xi_b^0} = (1.479 \pm 0.031) \times 10^{-12}$ s

Ξ_b DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$\Xi^- \ell^- \overline{\nu}_\ell X \times$ B($\overline{b} \to \Xi_b$)	$(3.9 \pm 1.2) \times 10^{-4}$	S=1.4	–
$J/\psi \Xi^- \times$ B($b \to \Xi_b^-$)	$(1.02^{+0.26}_{-0.21}) \times 10^{-5}$		1782
$J/\psi \Lambda K^- \times$ B($b \to \Xi_b^-$)	$(2.5 \pm 0.4) \times 10^{-6}$		1631
$p D^0 K^- \times$ B($\overline{b} \to \Xi_b$)	$(1.8 \pm 0.6) \times 10^{-6}$		2374
$p \overline{K}^0 \pi^- \times$ B($\overline{b} \to \Xi_b$)/B($\overline{b} \to B^0$)	$< 1.6 \times 10^{-6}$	CL=90%	2783
$p K^0 K^- \times$ B($\overline{b} \to \Xi_b$)/B($\overline{b} \to B^0$)	$< 1.1 \times 10^{-6}$	CL=90%	2730
$p K^- K^- \times$ B($\overline{b} \to \Xi_b$)	$(3.6 \pm 0.8) \times 10^{-8}$		2731
$\Lambda \pi^+ \pi^- \times$ B($b \to \Xi_b^0$)/B($b \to \Lambda_b^0$)	$< 1.7 \times 10^{-6}$	CL=90%	2781
$\Lambda K^- \pi^+ \times$ B($b \to \Xi_b^0$)/B($b \to \Lambda_b^0$)	$< 8 \times 10^{-7}$	CL=90%	2751
$\Lambda K^+ K^- \times$ B($b \to \Xi_b^0$)/B($b \to \Lambda_b^0$)	$< 3 \times 10^{-7}$	CL=90%	2698
$\Lambda_c^+ K^- \times$ B($\overline{b} \to \Xi_b$)	$(6 \pm 4) \times 10^{-7}$		2416
$\Lambda_b^0 \pi^- \times$ B($b \to \Xi_b^-$)/B($b \to \Lambda_b^0$)	$(5.7 \pm 2.0) \times 10^{-4}$		99

$\Xi_b'(5935)^-$

$J^P = \frac{1}{2}^+$

Mass $m = 5935.02 \pm 0.05$ MeV
$m_{\Xi_b'(5935)^-} - m_{\Xi_b^0} - m_{\pi^-} = 3.653 \pm 0.019$ MeV
Full width $\Gamma < 0.08$ MeV, CL = 95%

$\Xi_b'(5935)^-$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Xi_b^0 \pi^- \times$ B($\overline{b} \to \Xi_b'(5935)^-$)/B($\overline{b} \to \Xi_b^0$)	(11.8 ± 1.8) %	31

$\Xi_b(5945)^0$

$J^P = \frac{3}{2}^+$

Mass $m = 5949.8 \pm 1.4$ MeV
Full width $\Gamma = 0.90 \pm 0.18$ MeV

$\Xi_b(5955)^-$

$J^P = \frac{3}{2}^+$

Mass $m = 5955.33 \pm 0.13$ MeV
$m_{\Xi_b(5955)^-} - m_{\Xi_b^0} - m_{\pi^-} = 23.96 \pm 0.13$ MeV
Full width $\Gamma = 1.65 \pm 0.33$ MeV

$\Xi_b(5955)^-$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Xi_b^0 \pi^- \times$ B($\overline{b} \to \Xi_b^*(5955)^-$)/B($\overline{b} \to \Xi_b^0$)	(20.7 ± 3.5) %	84

Ω_b^-

$I(J^P) = 0(\frac{1}{2}^+)$
I, J, P need confirmation.

Mass $m = 6046.1 \pm 1.7$ MeV
$m_{\Omega_b^-} - m_{\Lambda_b^0} = 426.4 \pm 2.2$ MeV
$m_{\Omega_b^-} - m_{\Xi_b^-} = 247.3 \pm 3.2$ MeV
Mean life $\tau = (1.64^{+0.18}_{-0.17}) \times 10^{-12}$ s
$\tau(\Omega_b^-)/\tau(\Xi_b^-)$ mean life ratio $= 1.11 \pm 0.16$

Ω_b^- DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$J/\psi\, \Omega^- \times$B($b \to \Omega_b$)	$(2.9^{+1.1}_{-0.8}) \times 10^{-6}$		1806
$p K^- K^- \times$B($\overline{b} \to \Omega_b$)	$< 2.5 \times 10^{-9}$	90%	2866
$p \pi^- \pi^- \times$B($\overline{b} \to \Omega_b$)	$< 1.5 \times 10^{-8}$	90%	2943
$p K^- \pi^- \times$B($\overline{b} \to \Omega_b$)	$< 7 \times 10^{-9}$	90%	2915

b-baryon ADMIXTURE (Λ_b, Ξ_b, Σ_b, Ω_b)

These branching fractions are actually an average over weakly decaying b-baryons weighted by their production rates at the LHC, LEP, and Tevatron, branching ratios, and detection efficiencies. They scale with the b-baryon production fraction B($b \to b$-baryon).

The branching fractions B(b-baryon $\to \Lambda \ell^- \overline{\nu}_\ell$ anything) and B($\Lambda_b^0 \to \Lambda_c^+ \ell^- \overline{\nu}_\ell$ anything) are not pure measurements because the underlying measured products of these with B($b \to b$-baryon) were used to determine B($b \to b$-baryon), as described in the note "Production and Decay of b-Flavored Hadrons."

For inclusive branching fractions, *e.g.*, $B \to D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

b-baryon ADMIXTURE DECAY MODES (Λ_b,Ξ_b,Σ_b,Ω_b)	Fraction (Γ_i/Γ)	p (MeV/c)
$p \mu^- \overline{\nu}$ anything	$(5.5^{+2.2}_{-1.9})$ %	–
$p \ell \overline{\nu}_\ell$ anything	(5.3 ± 1.1) %	–
p anything	(66 ± 21) %	–
$\Lambda \ell^- \overline{\nu}_\ell$ anything	(3.6 ± 0.6) %	–
$\Lambda \ell^+ \nu_\ell$ anything	(3.0 ± 0.8) %	–
Λ anything	(37 ± 7) %	–
$\Xi^- \ell^- \overline{\nu}_\ell$ anything	$(6.2 \pm 1.6) \times 10^{-3}$	–

NOTES

This Summary Table only includes established baryons. The Particle Listings include evidence for other baryons. The masses, widths, and branching fractions for the resonances in this Table are Breit-Wigner parameters, but pole positions are also given for most of the N and Δ resonances.

For most of the resonances, the parameters come from various partial-wave analyses of more or less the same sets of data, and it is not appropriate to treat the results of the analyses as independent or to average them together.

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as S = $\sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame. For any resonance, the *nominal* mass is used in calculating p.

[*a*] The masses of the p and n are most precisely known in u (unified atomic mass units). The conversion factor to MeV, 1 u = 931.494061(21) MeV, is less well known than are the masses in u.

[*b*] The $|m_p - m_{\overline{p}}|/m_p$ and $|q_p + q_{\overline{p}}|/e$ are not independent, and both use the more precise measurement of $|q_{\overline{p}}/m_{\overline{p}}|/(q_p/m_p)$.

[*c*] The limit is from neutrality-of-matter experiments; it assumes $q_n = q_p + q_e$. See also the charge of the neutron.

[*d*] The μp and $e p$ values for the charge radius are much too different to average them. The disagreement is not yet understood.

[*e*] There is a lot of disagreement about the value of the proton magnetic charge radius. See the Listings.

[*f*] The first limit is for $p \to$ anything or "disappearance" modes of a bound proton. The second entry, a rough range of limits, assumes the dominant decay modes are among those investigated. For antiprotons the best limit, inferred from the observation of cosmic ray $\overline{p}$'s is $\tau_{\overline{p}} > 10^7$ yr, the cosmic-ray storage time, but this limit depends on a number of assumptions. The best direct observation of stored antiprotons gives $\tau_{\overline{p}}/\mathrm{B}(\overline{p} \to e^- \gamma) > 7 \times 10^5$ yr.

[*g*] There is some controversy about whether nuclear physics and model dependence complicate the analysis for bound neutrons (from which the best limit comes). The first limit here is from reactor experiments with free neutrons.

[*h*] Lee and Yang in 1956 proposed the existence of a mirror world in an attempt to restore global parity symmetry—thus a search for oscillations between the two worlds. Oscillations between the worlds would be maximal when the magnetic fields B and B' were equal. The limit for any B' in the range 0 to 12.5 μT is >12 s (95% CL).

[*i*] The parameters g_A, g_V, and g_{WM} for semileptonic modes are defined by $\overline{B}_f[\gamma_\lambda(g_V + g_A\gamma_5) + i(g_{WM}/m_{B_i})\,\sigma_{\lambda\nu}\,q^\nu]B_i$, and ϕ_{AV} is defined by $g_A/g_V = |g_A/g_V|e^{i\phi_{AV}}$. See the "Note on Baryon Decay Parameters" in the neutron Particle Listings in the Full *Review of Particle Physics*.

[*j*] Time-reversal invariance requires this to be 0° or 180°.

[*k*] This coefficient is zero if time invariance is not violated.

[*l*] This limit is for γ energies between 0.4 and 782 keV.

[*n*] The decay parameters γ and Δ are calculated from α and ϕ using

$$\gamma = \sqrt{1-\alpha^2}\,\cos\phi\,, \qquad \tan\Delta = -\frac{1}{\alpha}\,\sqrt{1-\alpha^2}\,\sin\phi\,.$$

See the "Note on Baryon Decay Parameters" in the neutron Particle Listings in the Full *Review of Particle Physics*.

[*o*] See Particle Listings in the Full *Review of Particle Physics* for the pion momentum range used in this measurement.

[*p*] The error given here is only an educated guess. It is larger than the error on the weighted average of the published values.

[*q*] A theoretical value using QED.

[*r*] This branching fraction includes all the decay modes of the final-state resonance.

[*s*] The value is for the sum of the charge states or particle/antiparticle states indicated.

[*t*] See AALTONEN 11H, Fig. 8, for the calculated ratio of $\Lambda_c^+ \pi^0 \pi^0$ and $\Lambda_c^+ \pi^+ \pi^-$ partial widths as a function of the $\Lambda_c(2595)^+ - \Lambda_c^+$ mass difference. At our value of the mass difference, the ratio is about 4.

[*u*] P_c^+ is a pentaquark-charmonium state.

[*v*] Not a pure measurement. See note at head of Λ_b^0 Decay Modes.

[*x*] Here h^- means π^- or K^-.

SEARCHES not in other sections

Magnetic Monopole Searches

Isolated supermassive monopole candidate events have not been confirmed. The most sensitive experiments obtain negative results.

Best cosmic-ray supermassive monopole flux limit:

$< 1.4 \times 10^{-16}$ cm^{-2}sr^{-1}s^{-1} for $1.1 \times 10^{-4} < \beta < 1$

Supersymmetric Particle Searches

All supersymmetric mass bounds here are model dependent.

The limits assume:

1) $\widetilde{\chi}^0_1$ is the lightest supersymmetric particle; 2) R-parity is conserved;

See the Particle Listings in the Full *Review of Particle Physics* for a Note giving details of supersymmetry.

$\widetilde{\chi}^0_i$ — neutralinos (mixtures of $\widetilde{\gamma}$, $\widetilde{Z}^0$, and $\widetilde{H}^0_i$)

Mass $m_{\widetilde{\chi}^0_1}$ > 0 GeV, CL = 95%
[general MSSM, non-universal gaugino masses]

Mass $m_{\widetilde{\chi}^0_1}$ > 46 GeV, CL = 95%
[all $\tan\beta$, all m_0, all $m_{\widetilde{\chi}^0_2} - m_{\widetilde{\chi}^0_1}$]

Mass $m_{\widetilde{\chi}^0_2}$ > 670 GeV, CL = 95%
[$3/4\ell + \not{E}_T$, Tn2n3B, $m_{\widetilde{\chi}^0_1} < 200$GeV]

Mass $m_{\widetilde{\chi}^0_3}$ > 670 GeV, CL = 95%
[$3/4\ell + \not{E}_T$, Tn2n3B, $m_{\widetilde{\chi}^0_1} < 200$GeV]

Mass $m_{\widetilde{\chi}^0_4}$ > 116 GeV, CL = 95%
[$1<\tan\beta<40$, all m_0, all $m_{\widetilde{\chi}^0_2} - m_{\widetilde{\chi}^0_1}$]

$\widetilde{\chi}^\pm_i$ — charginos (mixtures of $\widetilde{W}^\pm$ and $\widetilde{H}^\pm_i$)

Mass $m_{\widetilde{\chi}^\pm_1}$ > 94 GeV, CL = 95%
[$\tan\beta < 40$, $m_{\widetilde{\chi}^\pm_1} - m_{\widetilde{\chi}^0_1} > 3$ GeV, all m_0]

Mass $m_{\widetilde{\chi}^\pm_1}$ > 500 GeV, CL = 95%
[$2\ell^\pm + \not{E}_T$, Tchi1chi1B, $m_{\widetilde{\chi}^0_1} = 0$ GeV]

$\widetilde{\chi}^\pm$ — long-lived chargino

Mass $m_{\widetilde{\chi}^\pm}$ > 620 GeV, CL = 95% [stable $\widetilde{\chi}^\pm$]

$\widetilde{\nu}$ — sneutrino

Mass $m >$ 41 GeV, CL = 95% [model independent]

Mass $m >$ 94 GeV, CL = 95%
[CMSSM, $1 \leq \tan\beta \leq 40$, $m_{\widetilde{e}_R} - m_{\widetilde{\chi}^0_1} >10$ GeV]

Mass $m >$ 2300 GeV, CL = 95%
[RPV, $\widetilde{\nu}_\tau \to e\mu$, $\lambda'_{311} = 0.11$]

$\widetilde{e}$ — scalar electron (selectron)

Mass $m(\widetilde{e}_L) >$ 107 GeV, CL = 95% [all $m_{\widetilde{e}_L} - m_{\widetilde{\chi}_1^0}$]

Mass $m >$ 410 GeV, CL = 95%

[RPV, $\geq 4\ell^\pm$, $\widetilde{\ell} \rightarrow l\widetilde{\chi}_1^0$, $\widetilde{\chi}_1^0 \rightarrow \ell^\pm \ell^\mp \nu$]

$\widetilde{\mu}$ — scalar muon (smuon)

Mass $m >$ 94 GeV, CL = 95%

[CMSSM, $1 \leq \tan\beta \leq 40$, $m_{\widetilde{\mu}_R} - m_{\widetilde{\chi}_1^0} > 10$ GeV]

Mass $m >$ 410 GeV, CL = 95%

[RPV, $\geq 4\ell^\pm$, $\widetilde{\ell} \rightarrow l\widetilde{\chi}_1^0$, $\widetilde{\chi}_1^0 \rightarrow \ell^\pm \ell^\mp \nu$]

$\widetilde{\tau}$ — scalar tau (stau)

Mass $m >$ 81.9 GeV, CL = 95%

[$m_{\widetilde{\tau}_R} - m_{\widetilde{\chi}_1^0}$ >15 GeV, all θ_τ, B($\widetilde{\tau} \rightarrow \tau\widetilde{\chi}_1^0$) = 100%]

Mass $m >$ 286 GeV, CL = 95% [long-lived $\widetilde{\tau}$]

$\widetilde{q}$ – squarks of the first two quark generations

Mass $m >$ 1450 GeV, CL = 95%

[CMSSM, $\tan\beta = 30$, $A_0 = -2\max(m_0, m_{1/2})$, $\mu > 0$]

Mass $m >$ 1550 GeV, CL = 95%

[mass degenerate squarks]

Mass $m >$ 1050 GeV, CL = 95%

[single light squark bounds]

$\widetilde{q}$ — long-lived squark

Mass $m >$ 1000, CL = 95%

[$\widetilde{t}$, charge-suppressed interaction model]

Mass $m >$ 845, CL = 95% [$\widetilde{b}$, stable, Regge model]

$\widetilde{b}$ — scalar bottom (sbottom)

Mass $m >$ 1230 GeV, CL = 95%

[jets+$\not{E}_T$, Tsbot1, $m_{\widetilde{\chi}_1^0} = 0$ GeV]

$\widetilde{t}$ — scalar top (stop)

Mass $m >$ 1120 GeV, CL = 95%

[1ℓ+jets+$\not{E}_T$, Tstop1, $m_{\widetilde{\chi}_1^0} = 0$ GeV]

$\widetilde{g}$ — gluino

Mass $m >$ 1860 GeV, CL = 95%

[≥ 1 jets + $\not{E}_T$, Tglu1A, $m_{\widetilde{\chi}_1^0} = 0$ GeV]

Technicolor

The limits for technicolor (and top-color) particles are quite varied depending on assumptions. See the Technicolor section of the full *Review* (the data listings).

Quark and Lepton Compositeness, Searches for

Scale Limits Λ for Contact Interactions (the lowest dimensional interactions with four fermions)

If the Lagrangian has the form

$$\pm \frac{g^2}{2\Lambda^2} \overline{\psi}_L \gamma_\mu \psi_L \overline{\psi}_L \gamma^\mu \psi_L$$

(with $g^2/4\pi$ set equal to 1), then we define $\Lambda \equiv \Lambda^{\pm}_{LL}$. For the full definitions and for other forms, see the Note in the Listings on Searches for Quark and Lepton Compositeness in the full *Review* and the original literature.

$\Lambda^{+}_{LL}(e\,e\,e\,e)$	$>$ 8.3 TeV, CL = 95%
$\Lambda^{-}_{LL}(e\,e\,e\,e)$	$>$ 10.3 TeV, CL = 95%
$\Lambda^{+}_{LL}(e\,e\,\mu\,\mu)$	$>$ 8.5 TeV, CL = 95%
$\Lambda^{-}_{LL}(e\,e\,\mu\,\mu)$	$>$ 9.5 TeV, CL = 95%
$\Lambda^{+}_{LL}(e\,e\,\tau\,\tau)$	$>$ 7.9 TeV, CL = 95%
$\Lambda^{-}_{LL}(e\,e\,\tau\,\tau)$	$>$ 7.2 TeV, CL = 95%
$\Lambda^{+}_{LL}(\ell\ell\ell\ell)$	$>$ 9.1 TeV, CL = 95%
$\Lambda^{-}_{LL}(\ell\ell\ell\ell)$	$>$ 10.3 TeV, CL = 95%
$\Lambda^{+}_{LL}(e\,e\,q\,q)$	$>$ 24 TeV, CL = 95%
$\Lambda^{-}_{LL}(e\,e\,q\,q)$	$>$ 37 TeV, CL = 95%
$\Lambda^{+}_{LL}(e\,e\,u\,u)$	$>$ 23.3 TeV, CL = 95%
$\Lambda^{-}_{LL}(e\,e\,u\,u)$	$>$ 12.5 TeV, CL = 95%
$\Lambda^{+}_{LL}(e\,e\,d\,d)$	$>$ 11.1 TeV, CL = 95%
$\Lambda^{-}_{LL}(e\,e\,d\,d)$	$>$ 26.4 TeV, CL = 95%
$\Lambda^{+}_{LL}(e\,e\,c\,c)$	$>$ 9.4 TeV, CL = 95%
$\Lambda^{-}_{LL}(e\,e\,c\,c)$	$>$ 5.6 TeV, CL = 95%
$\Lambda^{+}_{LL}(e\,e\,b\,b)$	$>$ 9.4 TeV, CL = 95%
$\Lambda^{-}_{LL}(e\,e\,b\,b)$	$>$ 10.2 TeV, CL = 95%
$\Lambda^{+}_{LL}(\mu\,\mu\,q\,q)$	$>$ 20 TeV, CL = 95%
$\Lambda^{-}_{LL}(\mu\,\mu\,q\,q)$	$>$ 30 TeV, CL = 95%
$\Lambda(\ell\,\nu\,\ell\,\nu)$	$>$ 3.10 TeV, CL = 90%
$\Lambda(e\,\nu\,q\,q)$	$>$ 2.81 TeV, CL = 95%
$\Lambda^{+}_{LL}(q\,q\,q\,q)$	$>$ 13.1 none 17.4–29.5 TeV, CL = 95%
$\Lambda^{-}_{LL}(q\,q\,q\,q)$	$>$ 21.8 TeV, CL = 95%
$\Lambda^{+}_{LL}(\nu\,\nu\,q\,q)$	$>$ 5.0 TeV, CL = 95%
$\Lambda^{-}_{LL}(\nu\,\nu\,q\,q)$	$>$ 5.4 TeV, CL = 95%

Excited Leptons

The limits from $\ell^{*+}\ell^{*-}$ do not depend on λ (where λ is the $\ell\ell^*$ transition coupling). The λ-dependent limits assume chiral coupling.

$e^{*\pm}$ — excited electron

Mass $m >$ 103.2 GeV, CL = 95% (from $e^* e^*$)
Mass $m >$ 3.000×10^3 GeV, CL = 95% (from $e e^*$)
Mass $m >$ 356 GeV, CL = 95% (if $\lambda_\gamma = 1$)

$\mu^{*\pm}$ — excited muon

Mass $m >$ 103.2 GeV, CL = 95% (from $\mu^* \mu^*$)
Mass $m >$ 3.000×10^3 GeV, CL = 95% (from $\mu \mu^*$)

$\tau^{*\pm}$ — excited tau

Mass $m >$ 103.2 GeV, CL = 95% (from $\tau^* \tau^*$)
Mass $m >$ 2.500×10^3 GeV, CL = 95% (from $\tau \tau^*$)

ν^* — excited neutrino

Mass $m >$ 1.600×10^3 GeV, CL = 95% (from $\nu^* \nu^*$)
Mass $m >$ 213 GeV, CL = 95% (from $\nu^* X$)

q^* — excited quark

Mass $m >$ 338 GeV, CL = 95% (from $q^* q^*$)
Mass $m >$ 6.000×10^3 GeV, CL = 95% (from $q^* X$)

Color Sextet and Octet Particles

Color Sextet Quarks (q_6)

Mass $m >$ 84 GeV, CL = 95% (Stable q_6)

Color Octet Charged Leptons (ℓ_8)

Mass $m >$ 86 GeV, CL = 95% (Stable ℓ_8)

Color Octet Neutrinos (ν_8)

Mass $m >$ 110 GeV, CL = 90% ($\nu_8 \rightarrow \nu g$)

Extra Dimensions

Refer to the Extra Dimensions section of the full *Review* for a discussion of the model-dependence of these bounds, and further constraints.

Constraints on the radius of the extra dimensions, for the case of two-flat dimensions of equal radii

$R <$ 30 μm, CL = 95% (direct tests of Newton's law)
$R <$ 10.9 μm, CL = 95% ($pp \rightarrow jG$)
$R <$ 0.16–916 nm (astrophys.; limits depend on technique, assumptions)

Constraints on the fundamental gravity scale

$M_{TT} >$ 8.4 TeV, CL = 95% ($pp \rightarrow$ dijet, angular distribution)
$M_c >$ 4.16 TeV, CL = 95% ($pp \rightarrow \ell\overline{\ell}$)

Constraints on the Kaluza-Klein graviton in warped extra dimensions

$M_G >$ 4.1 TeV, CL = 95% ($pp \rightarrow \gamma\gamma$)

Constraints on the Kaluza-Klein gluon in warped extra dimensions

$M_{g_{KK}} >$ 2.5 TeV, CL = 95% ($g_{KK} \rightarrow t\overline{t}$)

TESTS OF CONSERVATION LAWS

Updated April 2018 by L. Wolfenstein (Carnegie-Mellon University), C.-J. Lin (LBNL) and E. Pianori (LBNL).

In the following text, we list the best limits from the Test of Conservation Laws table from the full *Review of Particle Physics.* Complete details are in that full *Review.* Limits in this text are for CL=90% unless otherwise specified. The Table is in two parts: "Discrete Space-Time Symmetries," *i.e.*, C, P, T, CP, and CPT; and "Number Conservation Laws," *i.e.*, lepton, baryon, hadronic flavor, and charge conservation. The references for these data can be found in the the Particle Listings in the *Review.* A discussion of these tests follows.

CPT INVARIANCE

General principles of relativistic field theory require invariance under the combined transformation CPT. The simplest tests of CPT invariance are the equality of the masses and lifetimes of a particle and its antiparticle. The best test comes from the limit on the mass difference between K^0 and $\overline{K}^0$. Any such difference contributes to the CP-violating parameter ϵ.

CP AND *T* INVARIANCE

Given CPT invariance, CP violation and T violation are equivalent. The original evidence for CP violation came from the measurement of $|\eta_{+-}| = |A(K^0_L \to \pi^+\pi^-)/A(K^0_S \to \pi^+\pi^-)| = (2.232 \pm 0.011) \times 10^{-3}$. This could be explained in terms of K^0–$\overline{K}^0$ mixing, which also leads to the asymmetry $[\Gamma(K^0_L \to \pi^- e^+ \nu) - \Gamma(K^0_L \to \pi^+ e^- \overline{\nu})]/[\text{sum}] = (0.334 \pm 0.007)\%$. Evidence for CP violation in the kaon decay amplitude comes from the measurement of $(1 - |\eta_{00}/\eta_{+-}|)/3 = Re(\epsilon'/\epsilon) = (1.66 \pm 0.23) \times 10^{-3}$. In the Standard Model much larger CP-violating effects are expected. The first of these, which is associated with B–$\overline{B}$ mixing, is the parameter $sin(2\beta)$ now measured quite accurately to be 0.679 ± 0.020. A number of other CP-violating observables are being measured in B decays; direct evidence for CP violation in the B decay amplitude comes from the asymmetry $[\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)]/[\text{sum}] = -0.082 \pm 0.006$. Direct tests of T violation are much more difficult; a measurement by CPLEAR of the difference between the oscillation probabilities of K^0 to $\overline{K^0}$ and $\overline{K^0}$ to K^0 is related to T violation [3]. A nonzero value of the electric dipole moment of the neutron and electron requires both P and T violation. The current experimental results are $< 3.0 \times 10^{-26}$ e cm (neutron), and $< 8.7 \times 10^{-29}$ e cm (electron) at the 90% C.L. The BABAR experiment reported the first direct observation of T violation in the B system. The measured T-violating parameters in the time evolution of the neutral B mesons are $\Delta S_T^+ = -1.37 \pm 0.15$ and $\Delta S_T^- = 1.17 \pm 0.21$, with a significance of 14σ [4]. This observation of T violation, with exchange of initial and final states of the neutral B, was made possible in a B-factory using the Einstein-Podolsky-Rosen Entanglement of the two B's produced in the decay of the $\Upsilon(4S)$ and the two time-ordered decays of the B's as filtering measurements of the meson state [5].

CONSERVATION OF LEPTON NUMBERS

Present experimental evidence and the standard electroweak theory are consistent with the absolute conservation of three separate lepton numbers: electron number L_e, muon number L_μ, and tau number L_τ, except for the effect of neutrino mixing associated with neutrino masses. Searches for violations are of the following types:

a) $\Delta L = 2$ for one type of charged lepton. The best limit comes from the search for neutrinoless double beta decay $(Z, A) \rightarrow (Z+2, A) + e^- + e^-$. The best laboratory limit is $t_{1/2} > 1.07 \times 10^{26}$ yr (CL=90%) for ^{136}Xe from the KamLAND-Zen experiment [6].

b) Conversion of one charged-lepton type to another. For purely leptonic processes, the best limits are on $\mu \rightarrow e\gamma$ and $\mu \rightarrow 3e$, measured as $\Gamma(\mu \rightarrow e\gamma)/\Gamma(\mu \rightarrow \text{all}) < 4.2 \times 10^{-13}$ and $\Gamma(\mu \rightarrow 3e)/\Gamma(\mu \rightarrow \text{all}) < 1.0 \times 10^{-12}$.

c) Conversion of one type of charged lepton into another type of charged antilepton. The case most studied is $\mu^- + (Z, A) \rightarrow e^+ + (Z-2, A)$, the strongest limit being $\Gamma(\mu^- \text{Ti} \rightarrow e^+ \text{Ca})/\Gamma(\mu^- \text{Ti} \rightarrow \text{all}) < 3.6 \times 10^{-11}$.

d) Neutrino oscillations. It is expected even in the standard electroweak theory that the lepton numbers are not separately conserved, as a consequence of lepton mixing analogous to Cabibbo-Kobayashi-Maskawa quark mixing. However, if the only source of lepton-number violation is the mixing of low-mass neutrinos then processes such as $\mu \rightarrow e\gamma$ are expected to have extremely small unobservable probabilities. For small neutrino masses, the lepton-number violation would be observed first in neutrino oscillations, which have been the subject of extensive experimental studies.

CONSERVATION OF HADRONIC FLAVORS

In strong and electromagnetic interactions, hadronic flavor is conserved, *i.e.* the conversion of a quark of one flavor (d, u, s, c, b, t) into a quark of another flavor is forbidden. In the Standard Model, the weak interactions violate these conservation laws in a manner described by the Cabibbo-Kobayashi-Maskawa mixing (see the section "Cabibbo-Kobayashi-Maskawa Mixing Matrix"). The way in which these conservation laws are violated is tested as follows:

(a) $\Delta S = \Delta Q$ rule. In the strangeness-changing semileptonic decay of strange particles, the strangeness change equals the change in charge of the hadrons. Tests come from limits on decay rates such as $\Gamma(\Sigma^+ \to n e^+ \nu)/\Gamma(\Sigma^+ \to \text{all}) < 5 \times 10^{-6}$, and from a detailed analysis of $K_L \to \pi e \nu$, which yields the parameter x, measured to be $(\text{Re}\, x, \text{Im}\, x) = (-0.002 \pm 0.006, 0.0012 \pm 0.0021)$. Corresponding rules are $\Delta C = \Delta Q$ and $\Delta B = \Delta Q$.

(b) Change of flavor by two units. In the Standard Model this occurs only in second-order weak interactions. The classic example is $\Delta S = 2$ via $K^0 - \overline{K}^0$ mixing. The $\Delta B = 2$ transitions in the B^0 and B^0_s systems via mixing are also well established. There is now strong evidence of $\Delta C = 2$ transition in the charm sector. with the mass difference All results are consistent with the second-order calculations in the Standard Model.

(c) Flavor-changing neutral currents. In the Standard Model the neutral-current interactions do not change flavor. The low rate $\Gamma(K_L \to \mu^+\mu^-)/\Gamma(K_L \to \text{all}) = (6.84 \pm 0.11) \times 10^{-9}$ puts limits on such interactions; the nonzero value for this rate is attributed to a combination of the weak and electromagnetic interactions. The best test should come from $K^+ \to \pi^+ \nu \overline{\nu}$. The LHCb and CMS experiments have recently observed the FCNC decay of $B^0_s \to \mu^+\mu^-$. The current world average value is $\Gamma(B^0_s \to \mu^+\mu^-)/\Gamma(B^0_s \to \text{all}) = (2.7^{+0.6}_{-0.5}) \times 10^{-9}$, which is consistent with the Standard Model expectation.

9. Quantum Chromodynamics

Revised September 2017 by S. Bethke (Max-Planck-Institute of Physics, Munich), G. Dissertori (ETH Zurich), and G.P. Salam (CERN).[1]

This update retains the 2016 summary of α_s values, as few new results were available at the deadline for this Review. Those and further new results will be included in the next update.

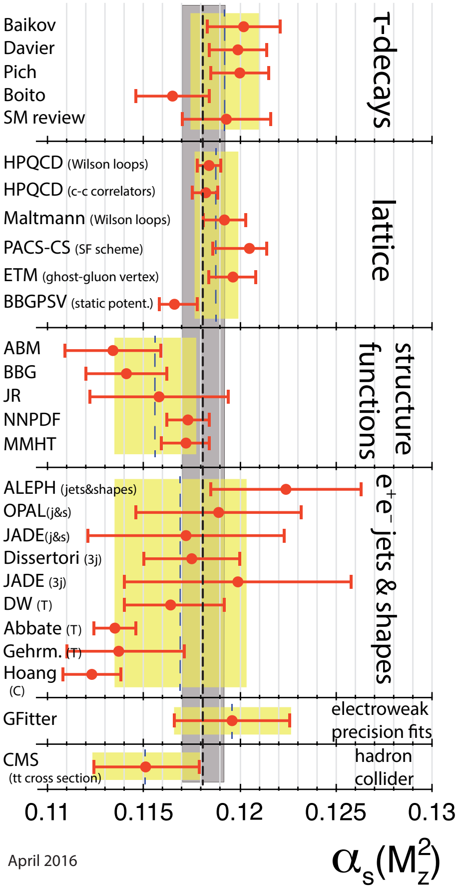


Figure 9.2: Summary of determinations of $\alpha_s(M_Z^2)$ from the six sub-fields discussed in the text. The yellow (light shaded) bands and dashed lines indicate the pre-average values of each sub-field. The dotted line and grey (dark shaded) band represent the final world average value of $\alpha_s(M_Z^2)$.

[1] On leave from LPTHE, UMR 7589, CNRS, Paris, France

10. Electroweak Model and Constraints on New Physics

Revised March 2018 by J. Erler (U. Mexico), A. Freitas (Pittsburgh U.).

The standard model of the electroweak interactions (SM) [1] is based on the gauge group SU(2) $\times$ U(1), with gauge bosons W^i_μ, $i = 1, 2, 3$, and B_μ for the SU(2) and U(1) factors, respectively, and the corresponding gauge coupling constants g and g'.

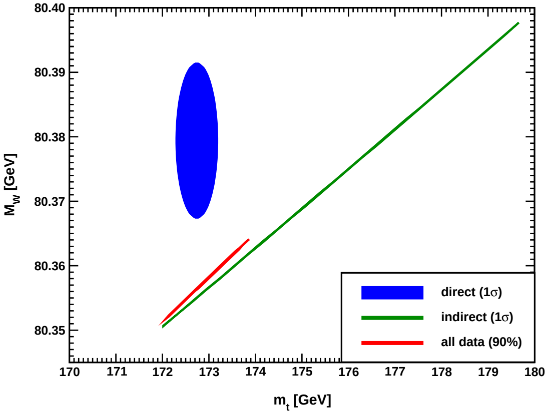


Figure 10.5: One-standard-deviation (39.35%) region in M_W as a function of m_t for the direct and indirect data, and the 90% CL region ($\Delta\chi^2 = 4.605$) allowed by all data.

Table 10.7: Values of $\hat{s}^2_Z$, s^2_W, α_s, m_t and M_H [both in GeV] for various data sets. In the fit to the LHC (Tevatron) data the α_s constraint is from the $t\bar{t}$ production [204] (inclusive jet [205]) cross-section.

Data	$\hat{s}^2_Z$	s^2_W	$\alpha_s(M_Z)$	m_t	M_H
All data	0.23122(3)	0.22332(7)	0.1187(16)	173.0 ± 0.4	125
All data except M_H	0.23107(9)	0.22310(19)	0.1190(16)	172.8 ± 0.5	90^{+17}_{-16}
All data except M_Z	0.23113(6)	0.22336(8)	0.1187(16)	172.8 ± 0.5	125
All data except M_W	0.23124(3)	0.22347(7)	0.1191(16)	172.9 ± 0.5	125
All data except m_t	0.23112(6)	0.22304(21)	0.1191(16)	176.4 ± 1.8	125
M_H, M_Z, Γ_Z, m_t	0.23125(7)	0.22351(13)	0.1209(45)	172.7 ± 0.5	125
LHC	0.23110(11)	0.22332(12)	0.1143(24)	172.4 ± 0.5	125
Tevatron + M_Z	0.23102(13)	0.22295(30)	0.1160(45)	174.3 ± 0.7	100^{+31}_{-26}
LEP	0.23138(17)	0.22343(47)	0.1221(31)	182 ± 11	274^{+376}_{-152}
SLD + M_Z, Γ_Z, m_t	0.23064(28)	0.22228(54)	0.1182(47)	172.7 ± 0.5	38^{+30}_{-21}
$A^{(b,c)}_{FB}$, M_Z, Γ_Z, m_t	0.23190(29)	0.22503(69)	0.1278(50)	172.7 ± 0.5	348^{+187}_{-124}
$M_{W,Z}$, $\Gamma_{W,Z}$, m_t	0.23103(12)	0.22302(25)	0.1192(42)	172.7 ± 0.5	84^{+22}_{-19}
low energy + $M_{H,Z}$	0.23176(94)	0.2254(35)	0.1185(19)	156 ± 29	125

Table 10.8: Values of the model-independent neutral-current parameters, compared with the SM predictions. There is a second $g_{LV,LA}^{\nu e}$ solution, given approximately by $g_{LV}^{\nu e} \leftrightarrow g_{LA}^{\nu e}$, which is eliminated by e^+e^- data under the assumption that the neutral current is dominated by the exchange of a single Z boson. In the SM predictions, the parametric uncertainties from M_Z, M_H, m_t, m_b, m_c, $\widehat{\alpha}(M_Z)$, and α_s are negligible.

Quantity	Experimental Value	Standard Model	Correlation	
$g_{LV}^{\nu e}$	-0.040 ± 0.015	-0.0398		-0.05
$g_{LA}^{\nu e}$	-0.507 ± 0.014	-0.5063		
$g_{AV}^{eu} + 2\, g_{AV}^{ed}$	0.4914 ± 0.0031	0.4950	-0.88	0.19
$2\, g_{AV}^{eu} - g_{AV}^{ed}$	-0.7148 ± 0.0068	-0.7194		-0.22
$2\, g_{VA}^{eu} - g_{VA}^{ed}$	-0.13 ± 0.06	-0.0954		
g_{VA}^{ee}	0.0190 ± 0.0027	0.0226		

The masses and decay properties of the electroweak bosons and low energy data can be used to search for and set limits on deviations from the SM.

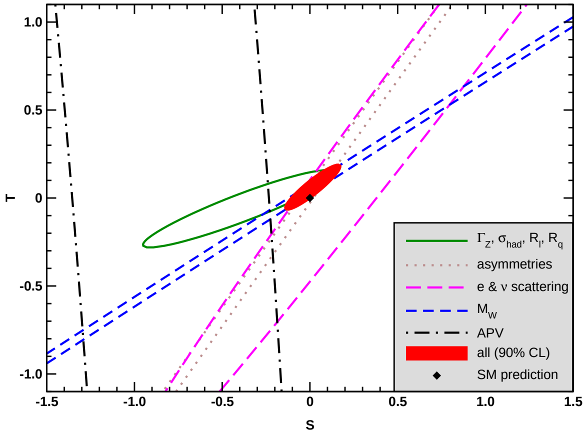


Figure 10.6: 1 σ constraints (39.35% for the closed contours and 68% for the others) on S and T (for $U = 0$) from various inputs combined with M_Z. S and T represent the contributions of new physics only. Data sets not involving M_W or Γ_W are insensitive to U. With the exception of the fit to all data, we fix $\alpha_s = 0.1187$. The black dot indicates the Standard Model values $S = T = 0$.

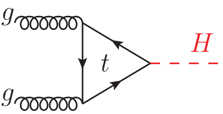
11. Status of Higgs Boson Physics

Revised August 2018 by M. Carena (Fermi National Accelerator Laboratory and the University of Chicago), C. Grojean (DESY, Hamburg, and Humboldt University, Berlin), M. Kado (Laboratoire de l'Accélérateur Linéaire, Orsay), and V. Sharma (University of California, San Diego).

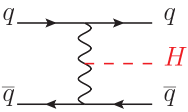
The discovery in 2012 by the ATLAS and the CMS collaborations of the Higgs boson was a major milestone as well as an extraordinary success of the LHC machine and the ATLAS and CMS experiments and an important step in the understanding of the mechanism that breaks the electroweak symmetry and generates of the masses of the known elementary particles. However, many theoretical questions remain unanswered and new conundrums about what lies behind the Higgs boson and beyond the Standard Model have come fore.

Since 2012 substantial progress has been made, yielding an increasingly precise profile of the properties of the Higgs boson, all being consistent with the Standard Model. And the Higgs boson has turned into a new tool to explore the manifestations of the SM and to probe the physics landscape beyond it.

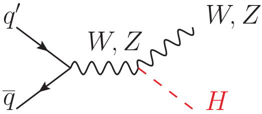
$$\sigma_{\rm tot}(H) = 55.1 \pm 2.4\,\mathrm{pb}$$



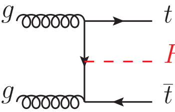
$\sigma(ggH) = 48.6 \pm 2.4\,\mathrm{pb}$



$\sigma(VBF) = 3.78 \pm 0.08\,\mathrm{pb}$



$\sigma(WH, ZH) = 1.37 \pm 0.03,\ 0.88 \pm 0.04\,\mathrm{pb}$



$\sigma(ttH) = 0.50^{+0.05}_{-0.07}\,\mathrm{pb}$

$$\Gamma = 4.07 \pm 0.16\,\mathrm{MeV}$$

$\mathrm{Br}(H \to b\bar{b}) = (58.4 \pm 1.9)\,\%$ $\mathrm{Br}(H \to WW) = (21.4 \pm 0.8)\,\%$

$\mathrm{Br}(H \to ZZ) = (2.6 \pm 0.11)\,\%$ $\mathrm{Br}(H \to \tau\bar{\tau}) = (6.3 \pm 3.6)\,\%$

$\mathrm{Br}(H \to \gamma\gamma) = (0.227 \pm 0.011)\,\%$ $\mathrm{Br}(H \to Z\gamma) = (0.153 \pm 0.013)\,\%$

$$\mathrm{Br}(H \to \mu\bar{\mu}) = (2.18 \pm 0.12) \times 10^{-4}$$

Figure: Main Leading Order Feynman diagrams contributing to the Higgs production at the LHC. The theoretical predictions for the production cross sections are also indicated at a centre-of-mass energy of 13 TeV assuming a Higgs boson mass of 125 GeV. The dominant decay modes are also reported.

Table: ATLAS (A) and CMS (C) measurements and limits. Rare modes results are reported as limits indicated in the column corresponding to the primary production mode, secondary production modes which are used in the analyses are indicated as "Incl.". Limits on invisible decays of the Higgs boson, indicated as "Inv.", are set on the invisible branching fraction. Limits are at 95% confidence level, the expected sensitivity is indicated in parentheses.

Decay mode	ggH	VBF	VH	ttH
$\gamma\gamma$ (A)	0.81 ± 0.18	2.0 ± 0.6	0.7 ± 0.8	1.4 ± 0.4
$\gamma\gamma$ (C)	1.10 ± 0.19	0.8 ± 0.6	2.4 ± 1.1	2.3 ± 0.8
4ℓ (A)	1.04 ± 0.17	2.8 ± 0.95	0.9 ± 1.0	< 1.8 68% CL
4ℓ (C)	1.20 ± 0.22	0.05 ± 0.04	0.0 ± 1.5	< 1.3 68% CL
WW^* (A)	1.21 ± 0.22	0.62 ± 0.36	3.2 ± 4.3	1.50 ± 0.61
WW^* (C)	1.38 ± 0.23	0.29 ± 0.48	3.27 ± 1.84	1.97 ± 0.67
$\tau^+\tau^-$ (A)	1.14 ± 0.44	0.98 ± 0.46	2.3 ± 1.6	1.36 ± 1.11
$\tau^+\tau^-$ (C)	1.2 ± 0.5	1.11 ± 0.34	-0.33 ± 1.02	0.28 ± 1.02
$b\bar{b}$ (A)	–	-3.9 ± 2.8	0.9 ± 0.27	0.83 ± 0.63
$b\bar{b}$ (C)	2.3 ± 1.66	2.8 ± 1.5	1.2 ± 0.4	0.82 ± 0.43
$\mu^+\mu^-$ (A)	$< 3.0\,(3.1)$	Incl.	–	–
$\mu^+\mu^-$ (C)	$< 2.6\,(1.9)$	–	–	–
$Z\gamma$ (A)	$< 6.6\,(5.2)$	Incl.	–	–
$Z\gamma, \gamma^*\gamma$ (C)	$< 3.9\,(2.9)$	Incl.	Incl.	–
Inv. (A)	–	<28% (31%)	<67% (39%)	–
Inv. (C)	Incl.	<24% (23%)	–	

The ATLAS and CMS experiments have made combined measurement of the mass of the Higgs boson in the diphoton and the four-lepton channels at per mille precision, $m_H = 125.09 \pm 0.24\,\mathrm{GeV}$. The quantum numbers of the Higgs boson have been probed in greater detail and show an excellent consistency with the $J^{PC} = 0^{++}$ hypothesis.

The coupling structure of the Higgs boson has been studied in a large number of channels, in the main production mechanisms at the LHC which are illustrated in the Figure. The Table summarises the ATLAS and CMS measurements and limits on the cross sections times branching fractions, normalised to their SM expectations in the main Higgs analysis channels. Further information on the couplings of the Higgs boson are also obtained from differential cross sections and searches for rare and exotic production and decay modes, including invisible decays.

All measurements are consistent with the SM predictions and provide stringent constraints on a large number of scenarios of new physics.

The review discusses in detail the latest developments in theories extending the SM to solve the fundamental questions raised by the existence of the Higgs boson.

12. CKM Quark-Mixing Matrix

Revised January 2018 by A. Ceccucci (CERN), Z. Ligeti (LBNL), and Y. Sakai (KEK).

Highlights from full review.

$$V_{\rm CKM} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}. \qquad (12.2)$$

This Cabibbo-Kobayashi-Maskawa (CKM) matrix [1,2] is a 3×3 unitary matrix. It can be parameterized [3] by three mixing angles and the CP-violating KM phase [2].

Using the Wolfenstein parameterization with $\lambda < 1$ we define [4–6]

$$\lambda = \frac{|V_{us}|}{\sqrt{|V_{ud}|^2 + |V_{us}|^2}}, \qquad A\lambda^2 = \lambda \left|\frac{V_{cb}}{V_{us}}\right|,$$

$$V_{ub}^* = A\lambda^3(\rho + i\eta) = \frac{A\lambda^3(\bar\rho + i\bar\eta)\sqrt{1 - A^2\lambda^4}}{\sqrt{1-\lambda^2}[1 - A^2\lambda^4(\bar\rho + i\bar\eta)]}. \qquad (12.4)$$

These ensure that $\bar\rho + i\bar\eta = -(V_{ud}V_{ub}^*)/(V_{cd}V_{cb}^*)$ is phase convention independent, and the CKM matrix written in terms of λ, A, $\bar\rho$, and $\bar\eta$ is unitary to all orders in λ. To $\mathcal{O}(\lambda^4)$

$$V_{\rm CKM} = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4). \qquad (12.5)$$

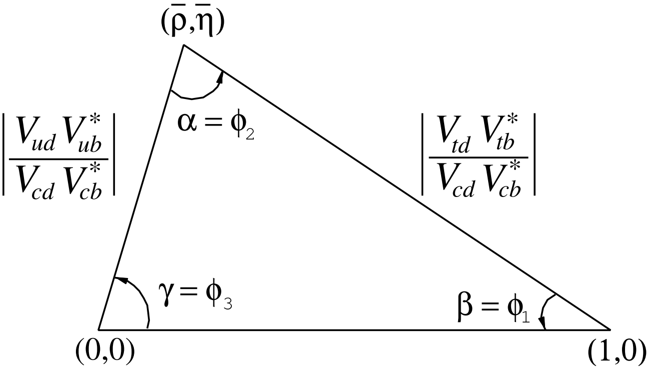


Figure 12.1: Sketch of the unitarity triangle.

The unitarity implies $\sum_i V_{ij}V_{ik}^* = \delta_{jk}$ and $\sum_j V_{ij}V_{kj}^* = \delta_{ik}$. The six vanishing combinations can be represented as triangles in a complex plane. The areas of all triangles are the same and are half of the Jarlskog invariant, J [7], which is a phase-convention-independent measure of CP violation, defined by $\mathrm{Im}\big[V_{ij}V_{kl}V_{il}^*V_{kj}^*\big] = J\sum_{m,n}\varepsilon_{ikm}\varepsilon_{jln}$.

The most commonly used unitarity triangle arises from

$$V_{ud}\,V_{ub}^* + V_{cd}\,V_{cb}^* + V_{td}\,V_{tb}^* = 0\,, \qquad (12.6)$$

by dividing each side by the best-known one, $V_{cd}V_{cb}^*$ (see Fig. 12.1).

Independently measured CKM elements and angles are

$$V_{\rm CKM} = \begin{pmatrix} 0.97420 \pm 0.00021 & 0.2243 \pm 0.0005 & 0.00394 \pm 0.00036 \\ 0.218 \pm 0.004 & 0.997 \pm 0.017 & 0.0422 \pm 0.0008 \\ 0.0081 \pm 0.0005 & 0.0394 \pm 0.0023 & 1.019 \pm 0.025 \end{pmatrix},$$

$$\sin(2\beta) = 0.691 \pm 0.017, \qquad \alpha = (84.5^{+5.9}_{-5.2})^\circ, \qquad \gamma = (73.5^{+4.2}_{-5.1})^\circ .$$

Using those values we can check the unitarity of the CKM matrix: $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9994 \pm 0.0005$ (1st row), $|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 = 1.043 \pm 0.034$ (2nd row), $|V_{ud}|^2 + |V_{cd}|^2 + |V_{td}|^2 = 0.9967 \pm 0.0018$ (1st column), and $|V_{us}|^2 + |V_{cs}|^2 + |V_{ts}|^2 = 1.046 \pm 0.034$ (2nd column).

12.4. Global fit in the Standard Model

A global fit with three generation unitarity constraints gives

$$\begin{aligned} \lambda &= 0.22453 \pm 0.00044\,, & A &= 0.836 \pm 0.015\,, \\ \bar\rho &= 0.122^{+0.018}_{-0.017}\,, & \bar\eta &= 0.355^{+0.012}_{-0.011}\,, \end{aligned} \qquad (12.26)$$

$$V_{\rm CKM} = \begin{pmatrix} 0.97446 \pm 0.00010 & 0.22452 \pm 0.00044 & 0.00365 \pm 0.00012 \\ 0.22438 \pm 0.00044 & 0.97359^{+0.00010}_{-0.00011} & 0.04214 \pm 0.00076 \\ 0.00896^{+0.00024}_{-0.00023} & 0.04133 \pm 0.00074 & 0.999105 \pm 0.000032 \end{pmatrix}, \qquad (12.27)$$

and the Jarlskog invariant of $J = (3.18 \pm 0.15) \times 10^{-5}$.

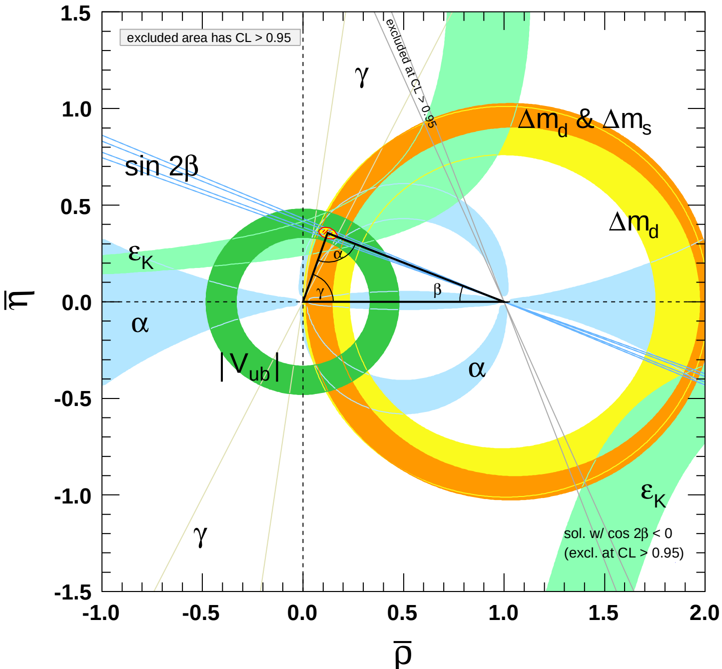


Figure 12.2: Constraints on the $\bar\rho, \bar\eta$ plane from various measurements and the global fit result. The shaded 95% CL regions all overlap consistently around the global fit region.

13. CP Violation in the Quark Sector

Revised August 2017 by T. Gershon (University of Warwick) and Y. Nir (Weizmann Institute).

Within the Standard Model, CP symmetry is broken by complex phases in the Yukawa couplings (that is, the couplings of the Higgs scalar to quarks). When all manipulations to remove unphysical phases in this model are exhausted, one finds that there is a single CP-violating parameter [17]. In the basis of mass eigenstates, this single phase appears in the 3×3 unitary matrix that gives the W-boson couplings to an up-type antiquark and a down-type quark. The beautifully consistent and economical Standard-Model description of CP violation in terms of Yukawa couplings, known as the Kobayashi-Maskawa (KM) mechanism [17], agrees with all measurements to date. (Pending verification, we do not discuss here a few measurements which are in tension with the predictions.) Furthermore, one can fit the data allowing new physics contributions to loop processes to compete with, or even dominate over, the Standard Model amplitudes [18,19]. Such analyses provide model-independent proof that the KM phase is different from zero, and that the matrix of three-generation quark mixing is the dominant source of CP violation in meson decays.

The current level of experimental accuracy and the theoretical uncertainties involved in the interpretation of the various observations leave room, however, for additional subdominant sources of CP violation from new physics. Indeed, almost all extensions of the Standard Model imply that there are such additional sources. Moreover, CP violation is a necessary condition for baryogenesis, the process of dynamically generating the matter-antimatter asymmetry of the Universe [20]. Despite the phenomenological success of the KM mechanism, it fails (by several orders of magnitude) to accommodate the observed asymmetry [21]. This discrepancy strongly suggests that Nature provides additional sources of CP violation beyond the KM mechanism. The expectation of new sources motivates the large ongoing experimental effort to find deviations from the predictions of the KM mechanism.

Using the notation M^0 to represent generically one of the K^0, D^0, B^0 or B_s^0 particles, we denote the state of an initially pure $|M^0\rangle$ or $|\overline{M}^0\rangle$ after an elapsed proper time t as $|M^0_{\rm phys}(t)\rangle$ or $|\overline{M}^0_{\rm phys}(t)\rangle$, respectively. Defining $x \equiv \Delta m/\Gamma$ and $y \equiv \Delta\Gamma/(2\Gamma)$, where Δm and $\Delta\Gamma$ are the mass and width differences between the two eigenstates of the effective Hamiltonian, $|M_L\rangle \propto \ p\,|M^0\rangle + q\,|\overline{M}^0\rangle$ and $|M_H\rangle \propto \ p\,|M^0\rangle - q\,|\overline{M}^0\rangle$, and Γ is their average width, one obtains the following time-dependent rates for decay to a final state f:

$$\begin{aligned}
&\frac{1}{e^{-\Gamma t}\mathcal{N}_f} d\Gamma\big[M^0_{\rm phys}(t) \to f\big]/dt = \\
&\qquad |A_f|^2 \left\{ \left(1+|\lambda_f|^2\right)\cosh(y\Gamma t) + \left(1-|\lambda_f|^2\right)\cos(x\Gamma t) \right. \\
&\qquad \left. +2\,\mathcal{R}e(\lambda_f)\sinh(y\Gamma t) - 2\,\mathcal{I}m(\lambda_f)\sin(x\Gamma t) \right\} , \\
&\frac{1}{e^{-\Gamma t}\mathcal{N}_f} d\Gamma\big[\overline{M}^0_{\rm phys}(t) \to f\big]/dt = \\
&\qquad |(p/q)A_f|^2 \left\{ \left(1+|\lambda_f|^2\right)\cosh(y\Gamma t) - \left(1-|\lambda_f|^2\right)\cos(x\Gamma t) \right.
\end{aligned}$$

$$+2\,\mathcal{R}e(\lambda_f)\sinh(y\Gamma t) + 2\,\mathcal{I}m(\lambda_f)\sin(x\Gamma t)\Big\}\ ,$$

where $\mathcal{N}_f$ is a normalization factor and $\lambda_f = (q/p)(\overline{A}_f/A_f)$ with A_f ($\overline{A}_f$) the amplitude for the M^0 ($\overline{M}^0$) $\to f$ decay. Considering the case that f is a CP eigenstate, we distinguish three types of CP-violating effects that can occur in the quark sector:

I. CP violation in decay, defined by $|\overline{A}_{\overline{f}}/A_f| \neq 1$.
II. CP violation in mixing, defined by $|q/p| \neq 1$.
III. CP violation in interference between decays with and without mixing, defined by $\arg(\lambda_f) \neq 0$.

It is also common to refer to *indirect CP violation* effects, which are consistent with originating from a single CP violating phase in neutral meson mixing, and *direct CP violation* effects, which cannot be explained in this way. CP violation in mixing (type II) is indirect; CP violation in decay (type I) is direct.

Many CP violating observables have been studied by experiments. Here we summarise only a sample of the most important measurements, including some parameters defined using common notation for the asymmetry between $\overline{B}^0_{\rm phys}(t)$ and $B^0_{\rm phys}(t)$ time-dependent decay rates

$$\mathcal{A}_f(t) = S_f \sin(\Delta m t) - C_f \cos(\Delta m t)\,,$$

where $S_f \equiv 2\,\mathcal{I}m(\lambda_f)/\left(1+|\lambda_f|^2\right)$, $C_f \equiv \left(1-|\lambda_f|^2\right)/\left(1+|\lambda_f|^2\right)$.

- Indirect CP violation in $K \to \pi\pi$ and $K \to \pi\ell\nu$ decays, given by
$$|\epsilon| = (2.228 \pm 0.011) \times 10^{-3}\,.$$
- Direct CP violation in $K \to \pi\pi$ decays, given by
$$\mathcal{R}e(\epsilon'/\epsilon) = (1.65 \pm 0.26) \times 10^{-3}\,.$$
- As yet, there is no significant signal of any category of CP violation in the properties and decays of charm hadrons.
- CP violation in the interference of mixing and decay in the tree-dominated $b \to c\bar{c}s$ transitions, such as $B^0 \to \psi K_S$, given by
$$S_{\psi K^0} = +0.691 \pm 0.017\,.$$
Within the Standard Model, this result can be interpreted with low theoretical uncertainty as measurement of $\sin(2\beta)$, where β is an angle of the unitarity triangle.
- The CP violation parameters in the $B^0 \to \pi^+\pi^-$ mode,
$$S_{\pi^+\pi^-} = -0.68 \pm 0.04\,, \quad C_{\pi^+\pi^-} = -0.27 \pm 0.04\,.$$
Together with measurements of other $B \to \pi\pi$ and similar decays, these result can be used to obtain constraints on the angle α of the unitarity triangle.
- Direct CP violation in $B^+ \to DK^+$ decays, where D_+ and $D_{K^-\pi^+}$ represent that the D meson is reconstructed in a CP-even and the suppressed $K^-\pi^+$ final state respectively,
$$\mathcal{A}_{B^+\to D_+K^+} = +0.129 \pm 0.012\,, \quad \mathcal{A}_{B^+\to D_{K^-\pi^+}K^+} = -0.41 \pm 0.06\,.$$
Together with measurements of other $B \to DK$ and similar decays, these result can be used to obtain constraints on the angle γ of the unitarity triangle.

14. Neutrino Masses, Mixing, and Oscillations

Updated November 2017 by K. Nakamura (Kavli IPMU (WPI), U. Tokyo, KEK), and S.T. Petcov (SISSA/INFN Trieste, Kavli IPMU (WPI), U. Tokyo, Bulgarian Academy of Sciences).

Highlights from full review.

All existing compelling data on neutrino oscillations can be described assuming 3-flavour neutrino mixing in vacuum. The (left-handed) fields of the flavour neutrinos ν_e, ν_μ and ν_τ in the expression for the weak charged lepton current in the CC weak interaction Lagrangian, are linear combinations of the LH components of the fields of three massive neutrinos ν_j:

$$\mathcal{L}_{\mathrm{CC}} = -\frac{g}{\sqrt{2}} \sum_{l=e,\mu,\tau} \overline{l_L}(x)\, \gamma_\alpha\, \nu_{lL}(x)\, W^{\alpha\dagger}(x) + h.c.,$$

$$\nu_{l\mathrm{L}}(x) = \sum_{j=1}^{3} U_{lj}\, \nu_{j\mathrm{L}}(x), \tag{14.5}$$

where U is the 3×3 unitary neutrino mixing matrix [4,5]. The mixing matrix U can be parameterized by 3 angles, and, depending on whether the massive neutrinos ν_j are Dirac or Majorana particles, by 1 or 3 CP violation phases [54,55]:

$$U = \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{bmatrix}$$

$$\times\, \mathrm{diag}(1,\ e^{i\frac{\alpha_{21}}{2}},\ e^{i\frac{\alpha_{31}}{2}})\ . \tag{14.6}$$

where $c_{ij} = \cos\theta_{ij}$, $s_{ij} = \sin\theta_{ij}$, the angles $\theta_{ij} = [0, \pi/2]$, $\delta = [0, 2\pi)$ is the Dirac CP violation phase and α_{21}, α_{31} are two Majorana CP violation (CPV) phases. Thus, in the case of massive Dirac neutrinos, the neutrino mixing matrix U is similar, in what concerns the number of mixing angles and CPV phases, to the CKM quark mixing matrix.

As we see, the fundamental parameters characterizing the 3-neutrino mixing are: i) the 3 angles θ_{12}, θ_{23}, θ_{13}, ii) depending on the nature of massive neutrinos ν_j - 1 Dirac (δ), or 1 Dirac + 2 Majorana ($\delta, \alpha_{21}, \alpha_{31}$), CPV phases, and iii) the 3 neutrino masses, m_1, m_2, m_3.

The neutrino oscillation probabilities depend in general, on the neutrino energy, E, the source-detector distance L, on the elements of U and, for relativistic neutrinos used in all neutrino experiments performed so far, on $\Delta m^2_{ij} \equiv (m_i^2 - m_j^2)$, $i \neq j$. In the case of 3-neutrino mixing there are only two independent neutrino mass squared differences, say $\Delta m^2_{21} \neq 0$ and $\Delta m^2_{31} \neq 0$. The numbering of massive neutrinos ν_j is arbitrary. It proves convenient from the point of view of relating the mixing angles θ_{12}, θ_{23} and θ_{13} to observables, to identify $|\Delta m^2_{21}|$ with the smaller of the two neutrino mass squared differences, which, as it follows from the data, is responsible for the solar ν_e and, the observed by KamLAND, reactor $\bar{\nu}_e$ oscillations.

The existing data do not allow one to determine the sign of $\Delta m^2_{31(32)}$. In the case of 3-neutrino mixing, the two possible signs of $\Delta m^2_{31(32)}$ correspond to two types of neutrino mass spectrum.

For the neutrino oscillation parameters values, see the Summary Table section in the Particle Listings.

Future progress

After the spectacular experimental progress made in the studies of neutrino oscillations, further understanding of the pattern of neutrino masses and neutrino mixing, of their origins and of the status of CP symmetry in the lepton sector requires an extensive and challenging program of research. The main goals of such a research program include:

- Determining the nature - Dirac or Majorana, of massive neutrinos ν_j. This is of fundamental importance for making progress in our understanding of the origin of neutrino masses and mixing and of the symmetries governing the lepton sector of particle interactions.
- Determination of the sign of Δm^2_{31} (or Δm^2_{32}), *i.e.*, the "neutrino mass ordering", or of the type of spectrum neutrino masses obey.
- Determining, or obtaining significant constraints on, the absolute scale of neutrino masses. This, in particular, would help obtain information about the detailed structure (hierarchical, quasidegenerate, etc.) of the neutrino mass spectrum.
- Determining the status of CP symmetry in the lepton sector.
- High precision measurement of θ_{13}, Δm^2_{21}, θ_{12}, $|\Delta m^2_{31}|$ and θ_{23}.
- Understanding at a fundamental level the mechanism giving rise to neutrino masses and mixing and to L_l-non-conservation. This includes understanding the origin of the patterns of ν-mixing and ν-masses suggested by the data. Are the observed patterns of ν-mixing and of $\Delta m^2_{21,31}$ related to the existence of a new fundamental symmetry of particle interactions? Is there any relation between quark mixing and neutrino mixing? What is the physical origin of CP violation phases in the neutrino mixing matrix U? Is there any relation (correlation) between the (values of) CP violation phases and mixing angles in U? Progress in the theory of neutrino mixing might also lead to a better understanding of the mechanism of generation of baryon asymmetry of the Universe.

The high precision measurement of the value of $\sin^2 2\theta_{13}$ from the Daya Bay experiment and the subsequent results on θ_{13} obtained by the RENO, Double Chooz and T2K collaborations (see Section 14.12), have far reaching implications. The measured relatively large value of θ_{13} opened up the possibilities, in particular,

i) for searching for CP violation effects in neutrino oscillation experiments with high intensity accelerator neutrino beams, like T2K, NOνA, etc.

ii) for determining the sign of Δm^2_{32}, and thus the type of neutrino mass spectrum ("neutrino mass ordering") in the long baseline neutrino oscillation experiments at accelerators (NOνA, etc.), in the experiments studying the oscillations of atmospheric neutrinos (PINGU [82], ORCA [83,84], Hyper-Kamiokande [200], INO [85]) , as well as in experiments with reactor antineutrinos [86–91].

There are also long term plans extending beyond 2025 for searches for CP violation and neutrino mass spectrum (ordering) determination in long baseline neutrino oscillation experiments with accelerator neutrino beams (see, *e.g.*, Refs. [93,94]) . The successful realization of this research program would be a formidable task and would require many years of extraordinary experimental efforts aided by intensive theoretical investigations and remarkable investments.

15. Quark Model

Revised August 2017 by C. Amsler (Stefan Meyer Institute for Subatomic Physics, Vienna), T. DeGrand (University of Colorado, Boulder), and B. Krusche (University of Basel).

The quarks are strongly interaction spin-1/2 fermions, whose parity is positive by convention. The charges of the u , c, and t quarks are $+2/3$, while those of the d, s, and b are $-1/3$. Their anti-quarks have the opposite charges and parities. By convention, the s quark is said to have negative strangeness and the c quark positive charm. The two lightest quarks, u and d, obey to a high degree an SU(2) symmetry called isospin, with u having $I_z = 1/2$ and d having $I_z = -1/2$. The other quarks can be assigned zero isospin.

Quarks have baryon number $\mathcal{B} = 1/3$, while anti-quarks have $\mathcal{B} = -1/3$. The mesons, which are pairs of quarks and anti-quarks, have $\mathcal{B} = 0$ and can be characterized by their intrinsic spin s, orbital angular momentum ℓ, and total spin J, lying between $|\ell - s|$ and $\ell + s$. The charge conjugation,or C, of meson is $(-1)^{\ell+s}$ while its parity is $(-1)^{\ell+1}$. G-parity combines the charge-conjugation and isospin symmetries: $G = Ce^{-i\pi I_y}$. Mesons made of a quark and its antiquark are G-parity eigenstates with $G = (-1)^{I+\ell+s}$.

The three lightest quarks, u, d, and s, respect an approximate symmetry, flavor SU(3), with quarks belonging to the $\mathbf{3}$ representation and anti-quarks to the $\overline{\mathbf{3}}$ representation. The quark-anti-quark states made from u, d, and s can be classified according to

$$\mathbf{3} \otimes \overline{\mathbf{3}} = \mathbf{8} \oplus \mathbf{1}. \tag{15.2}$$

A fourth quark such as charm c can be included by extending SU(3) to SU(4). However, SU(4) is badly broken owing to the much heavier c quark. Nevertheless, in an SU(4) classification, the sixteen mesons are grouped into a 15-plet and a singlet:

$$\mathbf{4} \otimes \overline{\mathbf{4}} = \mathbf{15} \oplus \mathbf{1}. \tag{15.3}$$

Baryons are made of three quarks (aside from a five-quark state recently observed at the LHC), allowing for more complex possibilities. The flavor SU(3) content of baryons made of u, d, and s is governed by

$$\mathbf{3} \otimes \mathbf{3} \otimes \mathbf{3} = \mathbf{10} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{1}. \tag{15.23}$$

The intrinsic spin of the three quarks yields either $s = 1/2$ or $s = 3/2$. The proton and neutron are members of an octet, while the spin-3/2 Δ^{++} is a member of a decuplet.

The strong interactions are described by the color SU(3) gauge theory, with each quark coming in three "colors." The color triplets interact through a color octet of gluons, gauge vector bosons. These are responsible for the formation of the bound states, mesons and baryons.

21. Big-Bang Cosmology

Revised September 2017 by K.A. Olive (University of Minnesota) and J.A. Peacock (University of Edinburgh).

21.1.1. *The Robertson-Walker Universe* :

The observed homogeneity and isotropy enable us to write the most general expression for a space-time metric which has a (3D) maximally symmetric subspace of a 4D space-time, known as the Robertson-Walker metric:

$$ds^2 = dt^2 - R^2(t)\left[\frac{dr^2}{1-kr^2} + r^2\left(d\theta^2 + \sin^2\theta\, d\phi^2\right)\right] . \tag{21.1}$$

Note that we adopt $c = 1$ throughout. By rescaling the radial coordinate, we can choose the curvature constant k to take only the discrete values $+1$, -1, or 0 corresponding to closed, open, or spatially flat geometries.

21.1.3. *The Friedmann equations of motion* :

The cosmological equations of motion are derived from Einstein's equations

$$\mathcal{R}_{\mu\nu} - \tfrac{1}{2} g_{\mu\nu}\mathcal{R} = 8\pi G_{\rm N} T_{\mu\nu} + \Lambda g_{\mu\nu} . \tag{21.6}$$

It is common to assume that the matter content of the Universe is a perfect fluid, for which

$$T_{\mu\nu} = -p g_{\mu\nu} + (p+\rho)\, u_\mu u_\nu , \tag{21.7}$$

where $g_{\mu\nu}$ is the space-time metric described by Eq. (21.1), p is the isotropic pressure, ρ is the energy density and $u = (1,0,0,0)$ is the velocity vector for the isotropic fluid in co-moving coordinates. With the perfect fluid source, Einstein's equations lead to the Friedmann equations

$$H^2 \equiv \left(\frac{\dot R}{R}\right)^2 = \frac{8\pi\, G_{\rm N}\, \rho}{3} - \frac{k}{R^2} + \frac{\Lambda}{3} , \tag{21.8}$$

and

$$\frac{\ddot R}{R} = \frac{\Lambda}{3} - \frac{4\pi G_{\rm N}}{3}\ (\rho + 3p) , \tag{21.9}$$

where $H(t)$ is the Hubble parameter and Λ is the cosmological constant. The first of these is sometimes called the Friedmann equation. Energy conservation via $T^{\mu\nu}_{\ \ ;\mu} = 0$, leads to a third useful equation

$$\dot\rho = -3H\,(\rho + p) . \tag{21.10}$$

Eq. (21.10) can also be simply derived as a consequence of the first law of thermodynamics.

21.1.5. *Standard Model solutions* :

Let us first assume a general equation of state parameter for a single component, $w = p/\rho$ which is constant. In this case, Eq. (21.10) can be written as $\dot\rho = -3(1+w)\rho\dot R/R$ and is easily integrated to yield

$$\rho \propto R^{-3(1+w)} . \tag{21.16}$$

Curvature domination occurs at rather late times (if a cosmological constant term does not dominate sooner). For $w \neq -1$,

$$R(t) \propto t^{2/[3(1+w)]} . \tag{21.17}$$

21.1.5.2. *A Radiation-dominated Universe:*

In the early hot and dense Universe, it is appropriate to assume an equation of state corresponding to a gas of radiation (or relativistic particles) for which $w = 1/3$. In this case, Eq. (21.16) becomes $\rho \propto R^{-4}$. Similarly, one can substitute $w = 1/3$ into Eq. (21.17) to obtain

$$R(t) \propto t^{1/2} \; ; \qquad H = 1/2t \; . \tag{21.18}$$

21.1.5.3. *A Matter-dominated Universe:*

Non-relativistic matter eventually dominates the energy density over radiation. A pressureless gas ($w = 0$) leads to the expected dependence $\rho \propto R^{-3}$, and, if $k = 0$, we get

$$R(t) \propto t^{2/3} \; ; \qquad H = 2/3t \; . \tag{21.19}$$

21.1.5.4. *A Universe dominated by vacuum energy:*

If there is a dominant source of vacuum energy, acting as a cosmological constant with equation of state $w = -1$. This leads to an exponential expansion of the Universe:

$$R(t) \propto e^{\sqrt{\Lambda/3}\, t} \; . \tag{21.20}$$

21.3. The Hot Thermal Universe

21.3.2. ***Radiation content of the Early Universe*** :

At the very high temperatures associated with the early Universe, massive particles are pair produced, and are part of the thermal bath. If for a given particle species i we have $T \gg m_i$, then we can neglect the mass and the thermodynamic quantities are easily computed. In general, we can approximate the energy density (at high temperatures) by including only those particles with $m_i \ll T$. In this case, we have

$$\rho = \left(\sum_{\mathrm{B}} g_{\mathrm{B}} + \frac{7}{8} \sum_{\mathrm{F}} g_{\mathrm{F}} \right) \frac{\pi^2}{30} T^4 \equiv \frac{\pi^2}{30} N(T)\, T^4 \; , \tag{21.42}$$

where $g_{\mathrm{B(F)}}$ is the number of degrees of freedom of each boson (fermion) and the sum runs over all boson and fermion states with $m \ll T$. Eq. (21.42) defines the effective number of degrees of freedom, $N(T)$, by taking into account new particle degrees of freedom as the temperature is raised.

The value of $N(T)$ at any given temperature depends on the particle physics model. In the standard SU(3)×SU(2)×U(1) model, we can specify $N(T)$ up to temperatures of $O(100)$ GeV. The change in N (ignoring mass effects) can be seen in the table below. At higher temperatures, $N(T)$ will be model-dependent.

In the radiation-dominated epoch, Eq. (21.10) can be integrated (neglecting the T-dependence of N) giving us a relationship between the age of the Universe and its temperature

$$t = \left(\frac{90}{32\pi^3 G_{\mathrm{N}} N(T)} \right)^{1/2} T^{-2} \; . \tag{21.43}$$

Put into a more convenient form

$$t\, T^2_{\mathrm{MeV}} = 2.4 [N(T)]^{-1/2} \; , \tag{21.44}$$

where t is measured in seconds and T_{MeV} in units of MeV.

Further discussion and all references may be found in the full *Review of Particle Physics*. The numbering of references and equations used here corresponds to that version.

26. Dark Matter

Revised Sept. 2017 by M. Drees (Bonn), G. Gerbier (Queen's, Canada).

Highlights from full review.

WIMPs should be gravitationally trapped inside galaxies and should have the adequate density profile to account for the observed rotational curves. These two constraints determine the main features of experimental detection of WIMPs. WIMPs interact with ordinary matter through elastic scattering on nuclei. With expected WIMP masses in the range 10 GeV to 10 TeV, typical nuclear recoil energies are of order of 1 to 100 keV.

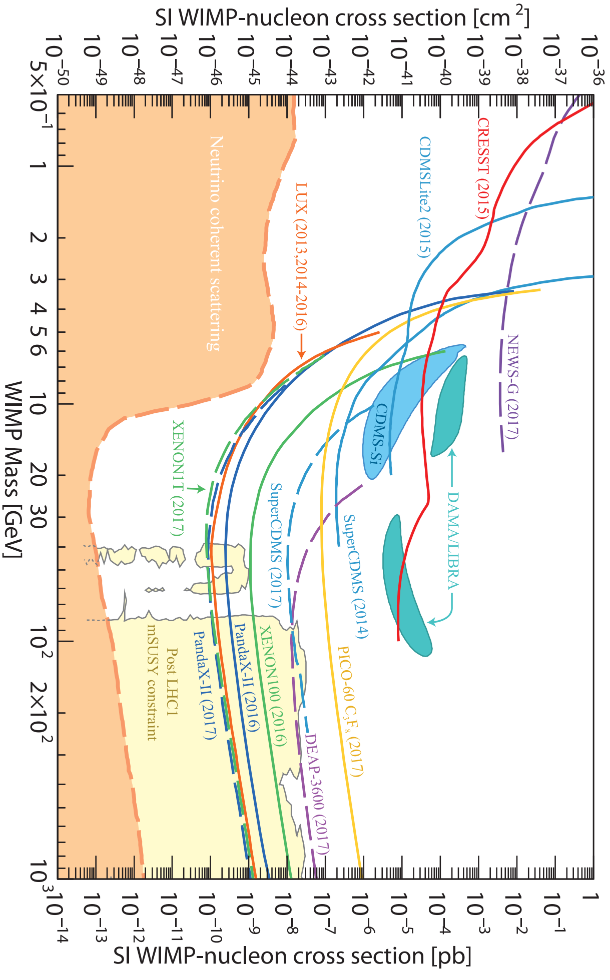


Figure 26.1: WIMP cross sections for spin-independent coupling versus mass. The DAMA/LIBRA and CDMS-Si enclosed areas are regions of interest from possible signal events. The yellow area shows a scan of the parameter space of 4 typical SUSY models.

28. Cosmic Microwave Background

Revised August 2017 by D. Scott (University of British Columbia) and G.F. Smoot (UCB/LBNL).

28.2. CMB Spectrum

It is well known that the spectrum of the microwave background is very precisely that of blackbody radiation, whose temperature evolves with redshift as $T(z) = T_0(1+z)$ in an expanding universe.

28.3. Description of CMB Anisotropies

Observations show that the CMB contains temperature anisotropies at the 10^{-5} level and polarization anisotropies at the 10^{-6} (and lower) level, over a wide range of angular scales. These anisotropies are usually expressed by using a spherical harmonic expansion of the CMB sky:

$$T(\theta,\phi) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\theta,\phi)$$

(with the linear polarization pattern written in a similar way using the so-called spin-2 spherical harmonics). Increasing angular resolution requires that the expansion goes to higher and higher multipoles. Because there are only very weak phase correlations seen in the CMB sky and since we notice no preferred direction, the vast majority of the cosmological information is contained in the temperature 2-point function, *i.e.*, the variance as a function only of angular separation. Equivalently, the power per unit $\ln\ell$ is $\ell \sum_m |a_{\ell m}|^2 / 4\pi$.

28.3.1. *The Monopole* :

The CMB has a mean temperature of $T_\gamma = 2.7255 \pm 0.0006\,\mathrm{K}$ (1σ) [21], which can be considered as the monopole component of CMB maps, a_{00}. Since all mapping experiments involve difference measurements, they are insensitive to this average level; monopole measurements can only be made with absolute temperature devices, such as the FIRAS instrument on the *COBE* satellite [22]. The measured kT_γ is equivalent to $0.234\,\mathrm{meV}$ or $4.60\times10^{-10}\,m_{\mathrm{e}}c^2$. A blackbody of the measured temperature has a number density $n_\gamma = (2\zeta(3)/\pi^2)\,T_\gamma^3 \simeq 411\,\mathrm{cm}^{-3}$, energy density $\rho_\gamma = (\pi^2/15)\,T_\gamma^4 \simeq 4.64\times10^{-34}\,\mathrm{g\,cm}^{-3} \simeq 0.260\,\mathrm{eV\,cm}^{-3}$, and a fraction of the critical density $\Omega_\gamma \simeq 5.38\times10^{-5}$.

28.3.2. *The Dipole* :

The largest anisotropy is in the $\ell = 1$ (dipole) first spherical harmonic, with amplitude $3.3645 \pm 0.0020\,\mathrm{mK}$ [12]. The dipole is interpreted to be the result of the Doppler boosting of the monopole caused by the solar system motion relative to the nearly isotropic blackbody field, as broadly confirmed by measurements of the radial velocities of local galaxies (*e.g.*, Ref. [23]).

28.3.3. *Higher-Order Multipoles* :

The variations in the CMB temperature maps at higher multipoles ($\ell \geq 2$) are interpreted as being mostly the result of perturbations in the density of the early Universe, manifesting themselves at the epoch of the last scattering of the CMB photons.

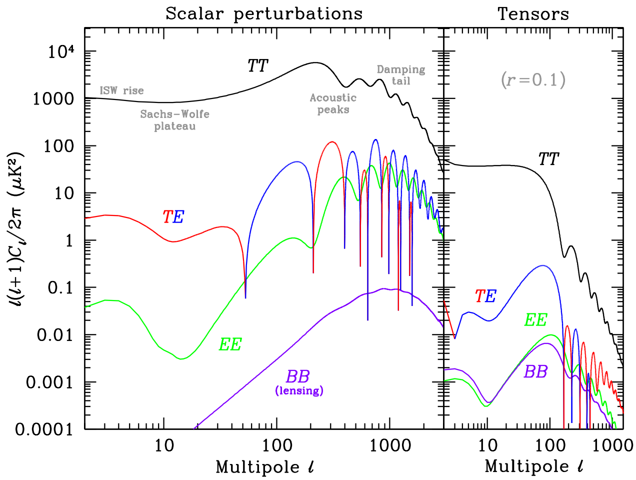


Figure 28.1: Theoretical CMB anisotropy power spectra, using the best-fitting ΛCDM model from *Planck*, calculated using `CAMB`. The panel on the left shows the theoretical expectation for scalar perturbations, while the panel on the right is for tensor perturbations, with an amplitude set to $r = 0.1$ for illustration.

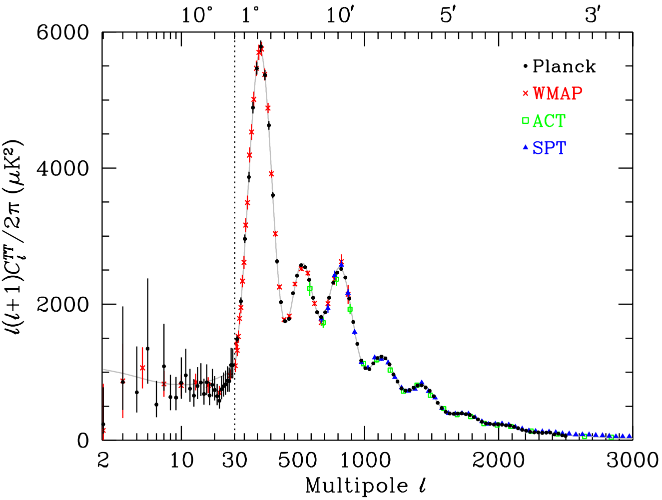


Figure 28.2: CMB temperature anisotropy band-power estimates from the *Planck*, *WMAP*, ACT, and SPT experiments. The acoustic peaks and damping region are very clearly observed, with no need for a theoretical curve to guide the eye; however, the curve plotted is the best-fit *Planck* ΛCDM model.

29. Cosmic Rays

Revised October 2017 by J.J. Beatty (Ohio State Univ.), J. Matthews (Louisiana State Univ.), and S.P. Wakely (Univ. of Chicago).

Cosmic ray spectra are expressed in terms of differential intensity I with units $[\mathrm{m}^{-2}\,\mathrm{s}^{-1}\mathrm{sr}^{-1}\mathcal{E}^{-1}]$, where the unit for $\mathcal{E}$ is chosen from energy per nucleon, energy per nucleus, and magnetic rigidity depending on the application.

Primary Cosmic Rays

The intensity of primary nucleons in the energy range from several GeV to somewhat beyond 100 TeV is given approximately by

$$I_N(E) \approx 1.8 \times 10^4 (E/1\ \mathrm{GeV})^{-\alpha} \frac{\text{nucleons}}{\mathrm{m}^2\ \mathrm{s\ sr\ GeV}} \tag{29.2}$$

where E is the energy-per-nucleon (including rest mass energy) and $\alpha = 2.7$ is the differential spectral index. About 74% of the primary nucleons are free protons and about 70% of the rest are bound in helium nuclei. At higher energies, the all-particle spectrum in terms of energy per *nucleus* is used. Above a few times 10^{15} eV the spectrum steepens at the 'knee', again steepens at a 'second knee' near 10^{17} eV, and flattens at the 'ankle' near $10^{18.5}$ eV. Above 5×10^{19} eV the spectrum steepens rapidly due to the onset of inelastic interactions with the cosmic microwave background.

Secondary Cosmic Rays at Sea Level

Cosmic rays at sea level are mostly muons from air showers induced by primary cosmic rays. The integral intensity of vertical muons above 1 GeV/c at sea level is $\approx 70\ \mathrm{m}^{-2}\,\mathrm{s}^{-1}\mathrm{sr}^{-1}$. The overall angular distribution of muons at the ground as a function of zenith angle θ is $\propto \cos^2\theta$. This results in a muon rate of about $1\ \mathrm{cm}^{-2}\,\mathrm{min}^{-1}$ for a thin horizontal detector. In addition to muons, there is a significant component of electrons and positrons with an integral vertical intensity very approximately 30, 6, and $0.2\ \mathrm{m}^{-2}\,\mathrm{s}^{-1}\mathrm{sr}^{-1}$ above 10, 100, and 1000 MeV respectively, with a complicated angular dependence. The integral intensity of vertical protons above 1 GeV/c at sea level is $\approx 0.9\ \mathrm{m}^{-2}\,\mathrm{sr}^{-1}$, accompanied by neutrons at about 1/3 of the proton flux.

Particles in the Atmosphere and Underground

At altitudes h between 1 and 6 km above sea level the vertical flux of particles with $E > 1$ GeV is dominated by muons with a flux of $\approx 100\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1} \times (h/\mathrm{km})^{0.42}$.

The underground charged particle flux is predominantly muons. For ice or water at depth $d > 1$ km the vertical flux is $\approx 2.2 \times 10^{-2}\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1} \times (d/\mathrm{km})^{-4.5}$. Below depths of ≈ 20 km w.e., most remaining muons are produced by neutrino interactions. The upward-going vertical intensity of muons above 2 GeV is $\approx 2 \times 10^{-9}\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$. The horizontal intensity below 20 km w.e. is about twice the upward-going vertical intensity.

For details and references see the full *Review of Particle Physics.*

30. Accelerator Physics of Colliders

Revised March 2018 by M.J. Syphers (NIU/FNAL) and F. Zimmermann (CERN).

The number of events, N_{exp}, is the product of the cross section of interest, σ_{exp}, and the time integral over the instantaneous *luminosity,* $\mathscr{L}$:

$$N_{exp} = \sigma_{exp} \times \int \mathscr{L}(t)dt. \tag{30.1}$$

Today's colliders all employ bunched beams. If two bunches containing n_1 and n_2 particles collide head-on with frequency $f_{\rm coll}$, a basic expression for the geometric luminosity is

$$\mathscr{L} = f_{\rm coll} \frac{n_1 n_2}{4\pi\sigma_x\sigma_y} \tag{30.2}$$

where σ_x and σ_y characterize the rms transverse beam sizes in the horizontal (bending) and vertical directions.

For a beam with a Gaussian distribution in x, x', the area containing one standard deviation σ_x, divided by π, is used as the definition of emittances:

$$\varepsilon_x \equiv \frac{\sigma_x^2}{\beta_x}, \tag{30.9}$$

with a corresponding expression in the other transverse direction, y.

Eq. (30.2) can be recast in terms of emittances and amplitude functions as

$$\mathscr{L} = f \frac{n_1 n_2}{4\pi\sqrt{\epsilon_x\,\beta_x^*\,\epsilon_y\,\beta_y^*}}\,\mathcal{F}. \tag{30.10}$$

Here, $\mathcal{F} \leq 1$ is a factor that takes into account effects such as crossing angles, hour glass factors, pinch effects, and so on. β^* is the value of the amplitude function at the interaction point.

A bunch in beam 1 presents a (nonlinear) lens to a particle in beam 2 resulting in changes to the particle's transverse tune with a range characterized by the beam-beam parameter

$$\xi_{y,2} = \left(\frac{\mu_0}{8\pi^2}\right) \frac{q_1 q_2 n_1 \beta_{y,2}^*}{m_{A,2}\gamma_2\sigma_{y,1}^*(\sigma_{x,1}^* + \sigma_{y,1}^*)} \tag{30.11}$$

where q_1 (q_2) denotes the particle charge of beam 1 (2) in units of the elementary charge, $m_{A,2}$ the mass of beam-2 particles, and μ_0 the vacuum permeability.

Eq. (30.2) for linear colliders can be written as:

$$\mathscr{L} \approx \frac{137}{8\pi r_e} \frac{P_{\rm wall}}{E_{cm}} \frac{\eta}{\sigma_y^*} N_\gamma H_D\,. \tag{30.12}$$

Here, $P_{\rm wall}$ is the total wall-plug power of the collider, $\eta \equiv P_b/P_{\rm wall}$ the efficiency of converting wall-plug power into beam power $P_b = f_{\rm coll} n E_{cm}$, E_{cm} the cms energy, n $(= n_1 = n_2)$ the bunch population, and σ_y^* the vertical rms beam size at the collision point. In formulating Eq. (30.12) the number of beamstrahlung photons emitted per $e^\pm$, was approximated as $N_\gamma \approx 2\alpha r_e n/\sigma_x^*$, where $\alpha \approx 1/137$ denotes the fine-structure constant.

Tentative parameters of selected future high-energy colliders. Parameters associated with different beam energy scenarios are comma-separated. Quantities are, where appropriate, r.m.s.; H and V indicate horizontal and vertical directions. See full *Review* for complete tables. Parameters for other proposed high-energy colliders, including a muon collider, can be found in the full *Review*.

	FCC-ee	CEPC	ILC	LHeC	HE-LHC	FCC-hh
Species	e^+e^-	e^+e^-	e^+e^-	ep	pp	pp
Beam energy (TeV)	0.46, 0.120, 0.183	0.46, 0.120	0.125, 0.25	0.06(e), 7 (p)	13.5	50
Circumference / Length (km)	97.75	100	20.5, 31	9(e), 26.7 (p)	26.7	97.75
Interaction regions	2	2	1	1	2 (4)	4
Luminosity (10^{34} cm^{-2} s^{-1})	200, 7, 1.5	32, 3	1.4, 1.8	0.8	28	5–30
Time between collisions (μs)	0.015, 0.75, 8.5	0.025, 0.68	0.55	0.025	0.025	0.025
Bunch length (rms, mm)	12.1, 5.3, 3.8	8.5, 3.3	0.3	0.06 (e), 75.5(p)	80	80
IP beam size (μm)	H: 6.3, 14, 38 V: 0.03, 0.04, 0.07	H: 5.9, 21 V: 0.04, 0.07	H: 0.52, 0.47 V: 0.008, 0.006	4.3 (round)	6.6	6.8 (init.)
β^*, amplitude function at interaction point (cm)	H: 15, 30, 100 V: 0.08, 0.1, 0.16	H: 20, 36 V: 0.1, 0.15	H: 1.3, 2.2 V: 0.041, 0.048	5.0(e), 7.0(p)	25	110–30
RF frequency (MHz)	400, 400, 800	650	1300	800(e), 400(p)	400	400
Particles per bunch (10^{10})	17, 15, 27	8, 15	2	0.23(e), 22(p)	10	10
Average beam current (mA)	1390, 29, 5.4	19.2	6 (in train)	15(e), 883(p)	1120	500
SR power loss (MW)	100	64	n/a	30(e), 0.01(p)	0.1	2.4

31. High-Energy Collider Parameters

Updated in March 2018 with numbers received from representatives of the colliders (contact E. Pianori, LBNL). Except for SuperKEKB, where design values are quoted, the table shows parameter values as achieved by March 1, 2018. Quantities are, where appropriate, r.m.s.; energies refer to beam energy; H and V indicate horizontal and vertical directions. Only selected colliders operating in 2016 and 2017 are included. See full *Review* for complete tables.

	VEPP-2000 (Novosibirsk)	VEPP-4M (Novosibirsk)	BEPC-II (China)	DAΦNE (Frascati)	SuperKEKB (KEK)	LHC (CERN)
Physics start date	2010	1994	2008	1999	2018	2015
Particles collided	e^+e^-	e^+e^-	e^+e^-	e^+e^-	e^+e^-	pp
Maximum beam energy (GeV)	1.0	6	1.89 (2.3 max)	0.510	e^-: 7, e^+: 4	6500
Luminosity (10^{30} cm^{-2}s^{-1})	40	20	1000	453	8×10^5	2×10^4
Time between collisions (ns)	40	600	8	2.7	4	24.95
Energy spread (units 10^{-3})	0.71	1	0.52	0.40	e^-/e^+: 0.64/0.81	0.105
Bunch length (cm)	4	5	≈ 1.2	1 - 2	e^-/e^+: 0.5/0.6	8
Beam radius (10^{-6} m)	125 (round)	H: 1000 V: 30	H: 347 V: 4.5	H: 260 V: 4.8	e^-: 11 (H), 0.062 (V) e^+: 10 (H), 0.048 (V)	10
Free space at interaction point (m)	± 0.5	± 2	± 0.63	± 0.295	e^- : $+1.20/-1.28$ e^+ : $+0.78/-0.73$	38
β^*, amplitude function at interaction point (m)	H: $0.05-0.11$ V: $0.05-0.11$	H: 0.75 V: 0.05	H: 1.0 V: 0.0129	H: 0.26 V: 0.009	e^-: 0.025 (H), 3×10^{-4} (V) e^+: 0.032 (H), 2.7×10^{-4} (V)	0.3
Interaction regions	2	1	1	1	1	4

33. Passage of Particles Through Matter

Revised August 2015 by H. Bichsel (University of Washington), D.E. Groom (LBNL), and S.R. Klein (LBNL).

This review covers the interactions of photons and electrically charged particles in matter, concentrating on energies of interest for high-energy physics and astrophysics and processes of interest for particle detectors.

Table 33.1: Summary of variables used in this section. The kinematic variables β and γ have their usual relativistic meanings.

Symbol	Definition	Value or (usual) units
$m_e c^2$	electron mass $\times c^2$	0.510 998 9461(31) MeV
r_e	classical electron radius $e^2/4\pi\epsilon_0 m_e c^2$	2.817 940 3227(19) fm
α	fine structure constant $e^2/4\pi\epsilon_0 \hbar c$	1/137.035 999 139(31)
N_A	Avogadro's number	$6.022\,140\,857(74) \times 10^{23}$ mol^{-1}
ρ	density	g cm^{-3}
x	mass per unit area	g cm^{-2}
M	incident particle mass	MeV/c^2
E	incident part. energy $\gamma M c^2$	MeV
T	kinetic energy, $(\gamma - 1)Mc^2$	MeV
W	energy transfer to an electron in a single collision	MeV
k	bremsstrahlung photon energy	MeV
z	charge number of incident particle	
Z	atomic number of absorber	
A	atomic mass of absorber	g mol^{-1}
K	$4\pi N_A r_e^2 m_e c^2$ (Coefficient for dE/dx)	0.307 075 MeV mol^{-1} cm^2
I	mean excitation energy	eV (*Nota bene!*)
$\delta(\beta\gamma)$	density effect correction to ionization energy loss	
$\hbar\omega_p$	plasma energy $\sqrt{4\pi N_e r_e^3}\; m_e c^2/\alpha$	$\sqrt{\rho\,\langle Z/A\rangle} \times 28.816$ eV $\hookrightarrow$ ρ in g cm^{-3}
N_e	electron density	(units of r_e)$^{-3}$
w_j	weight fraction of the jth element in a compound or mixture	
n_j	$\propto$ number of jth kind of atoms in a compound or mixture	
X_0	radiation length	g cm^{-2}
E_c	critical energy for electrons	MeV
$E_{\mu c}$	critical energy for muons	GeV
E_s	scale energy $\sqrt{4\pi/\alpha}\; m_e c^2$	21.2052 MeV
R_M	Molière radius	g cm^{-2}

33.2. Electronic energy loss by heavy particles [1–33]

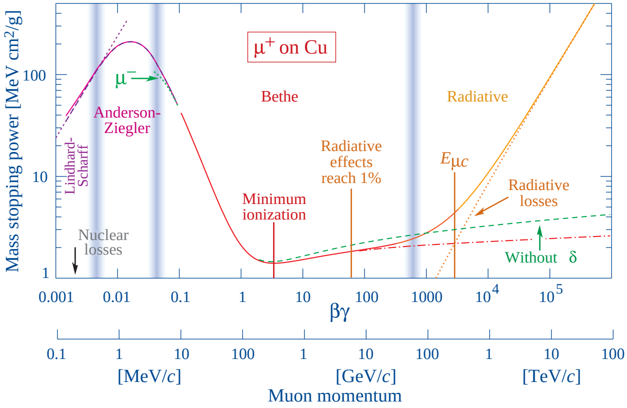


Figure 33.1: Mass stopping power ($= \langle -dE/dx \rangle$) for positive muons in copper as a function of $\beta\gamma = p/Mc$ over nine orders of magnitude in momentum (12 orders of magnitude in kinetic energy). Vertical bands indicate boundaries between different approximations discussed in the text.

33.2.2. *Maximum energy transfer in a single collision* :

For a particle with mass M,

$$W_{\max} = \frac{2m_e c^2\, \beta^2\gamma^2}{1 + 2\gamma m_e/M + (m_e/M)^2} \; . \tag{33.4}$$

33.2.3. *Stopping power at intermediate energies* :

The mean rate of energy loss by moderately relativistic charged heavy particles is well-described by the "Bethe equation,"

$$\left\langle -\frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right] \; . \tag{33.5}$$

This is the *mass stopping power*; with the symbol definitions and values given in Table 33.1, the units are MeV g^{-1}cm^2. $\langle -dE/dx \rangle$ defined in this way is about the same for most materials, decreasing slowly with Z. The *linear stopping power*, in MeV/cm, is $\langle -dE/dx \rangle \, \rho$, where ρ is the density in g/cm^3.

As the particle energy increases, its electric field flattens and extends, so that the distant-collision contribution to Eq. (33.5) increases as $\ln \beta\gamma$. However, real media become polarized, limiting the field extension and effectively truncating this part of the logarithmic rise. Parameterization of the density effect term $\delta(\beta\gamma)$ in Eq. (33.5) is discussed in the full *Review* .

Few concepts in high-energy physics are as misused as $\langle dE/dx \rangle$. The mean is weighted by very rare events with large single-collision energy deposits. Even with samples of hundreds of events a dependable value for the mean energy loss cannot be obtained. Far better and more easily measured is the most probable energy loss, discussed below.

Although it must be used with cautions and caveats, $\langle dE/dx \rangle$ as described in Eq. (33.5) still forms the basis of much of our understanding of energy loss by charged particles. Extensive tables are available [pdg.lbl.gov/AtomicNuclearProperties/].

Eq. (33.5) may be integrated to find the total (or partial) "continuous slowing-down approximation" (CSDA) range R. Since dE/dx depends (nearly) only on β, R/M is a function of E/M or pc/M.

33.2.9. *Fluctuations in energy loss* :

For detectors of moderate thickness x (*e.g.* scintillators or LAr cells), the energy loss probability distribution $f(\Delta;\beta\gamma,x)$ is adequately described by the highly-skewed Landau (or Landau-Vavilov) distribution [24,25]. The most probable energy loss

$$\Delta_p = \xi\left[\ln\frac{2mc^2\beta^2\gamma^2}{I} + \ln\frac{\xi}{I} + j - \beta^2 - \delta(\beta\gamma)\right] , \qquad (33.11)$$

where $\xi = (K/2)\,\langle Z/A\rangle\, z^2(x/\beta^2)$ MeV for a detector with a thickness x in g cm^{-2}, and $j = 0.200$ [26]. While dE/dx is independent of thickness, Δ_p/x scales as $a\ln x + b$. This most probable energy loss reaches a (Fermi) plateau rather than continuing $\langle dE/dx\rangle$'s lograthmic rise with increasing energy.

33.4. Photon and electron interactions in matter

At low energies electrons and positrons primarily lose energy by ionization, although other processes (Møller scattering, Bhabha scattering, e^+ annihilation) contribute. While ionization loss rates rise logarithmically with energy, bremsstrahlung losses rise nearly linearly (fractional loss is nearly independent of energy), and dominates above the critical energy (Sec. 33.4.4 below), a few tens of MeV in most materials

33.4.1. *Collision energy losses by $e^\pm$* :

Stopping power differs somewhat for electrons and positrons, and both differ from stopping power for heavy particles because of the kinematics, spin, charge, and the identity of the incident electron with the electrons that it ionizes. Complete discussions and tables can be found in Refs. 10, 11, and 29 in the full *Review*.

33.4.2. *Radiation length* :

High-energy electrons predominantly lose energy in matter by bremsstrahlung, and high-energy photons by e^+e^- pair production. The characteristic amount of matter traversed for these related interactions is called the radiation length X_0, usually measured in g cm^{-2}. X_0 has been calculated and tabulated by Y.S. Tsai [42]:

$$\frac{1}{X_0} = 4\alpha r_e^2\frac{N_A}{A}\left\{Z^2\left[L_{\rm rad} - f(Z)\right] + Z\,L'_{\rm rad}\right\} . \qquad (33.26)$$

For $A = 1$ g mol^{-1}, $4\alpha r_e^2 N_A/A = (716.408\ \text{g cm}^{-2})^{-1}$. $L_{\rm rad}$ and $L'_{\rm rad}$ are tabulated in the full *Review*, where a 4-place approximation for $f(z)$ is also given.

33.4.3. *Bremsstrahlung energy loss by $e^\pm$* :

At very high energies and except at the high-energy tip of the bremsstrahlung spectrum, the cross section can be approximated in the "complete screening case" as [42]

$$\begin{aligned} d\sigma/dk = (1/k)4\alpha r_e^2\{&(\tfrac{4}{3} - \tfrac{4}{3}y + y^2)[Z^2(L_{\rm rad} - f(Z)) + Z\,L'_{\rm rad}] \\ &+ \tfrac{1}{9}(1-y)(Z^2+Z)\} , \end{aligned} \qquad (33.29)$$

where $y = k/E$ is the fraction of the electron's energy transferred to the radiated photon. At small y (the "infrared limit") the term on the second line ranges from 1.7% (low Z) to 2.5% (high Z) of the total. If it is ignored and the first line simplified with the definition of X_0 given in Eq. (33.26), we have

$$\frac{d\sigma}{dk} = \frac{A}{X_0 N_A k}\left(\tfrac{4}{3} - \tfrac{4}{3}y + y^2\right) . \tag{33.30}$$

33.4.4. *Critical energy* :

An electron loses energy by bremsstrahlung at a rate nearly proportional to its energy, while the ionization loss rate varies only logarithmically with the electron energy. The *critical energy* E_c is sometimes defined as the energy at which the two loss rates are equal [49]. Among alternate definitions is that of Rossi [2], who defines the critical energy as the energy at which the ionization loss per radiation length is equal to the electron energy. Equivalently, it is the same as the first definition with the approximation $|dE/dx|_{\rm brems} \approx E/X_0$. This form has been found to describe transverse electromagnetic shower development more accurately.

Values of E_c for electrons can be reasonaby well described by $(610~{\rm MeV})/(Z + 1.24)$ for solids and $(710~{\rm MeV})/(Z + 0.92)$ for gases. E_c for both electrons and positrons in more than 350 materials can be found at `pdg.lbl.gov/AtomicNuclearProperties`.

33.4.5. *Energy loss by photons* :

At low energies the photoelectric effect dominates, although Compton scattering, Rayleigh scattering, and photonuclear absorption also contribute. The photoelectric cross section is characterized by discontinuities (absorption edges) as thresholds for photoionization of various atomic levels are reached. Pair production dominates at high energies, but is supressed at ultrahigh energies because of quantum mechanical interference between amplitudes from different scattering centers (LPM effect).

At still higher photon and electron energies, where the bremsstrahlung and pair production cross-sections are heavily suppressed by the LPM effect, photonuclear and electronuclear interactions predominate over electromagnetic interactions. At photon energies above about 10^{20} eV, for example, photons usually interact hadronically.

33.5. Electromagnetic cascades

When a high-energy electron or photon is incident on a thick absorber, it initiates an electromagnetic cascade as pair production and bremsstrahlung generate more electrons and photons with lower energies.

The longitudinal development is governed by the high-energy part of the cascade, and therefore scales as the radiation length in the material. Electron energies eventually fall below the critical energy, and then dissipate their energy by ionization and excitation rather than by the generation of more shower particles. In describing shower behavior, it is convenient to introduce the scale variables

$$t = x/X_0 \ , \qquad\qquad y = E/E_c \ , \tag{33.35}$$

so that distance is measured in units of radiation length and energy in units of critical energy.

The mean longitudinal profile of the energy deposition in an electromagnetic cascade is reasonably well described by a gamma distribution [59],

$$\frac{dE}{dt} = E_0\, b\, \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)} \ , \tag{33.36}$$

at energies from 1 GeV to 100 GeV.

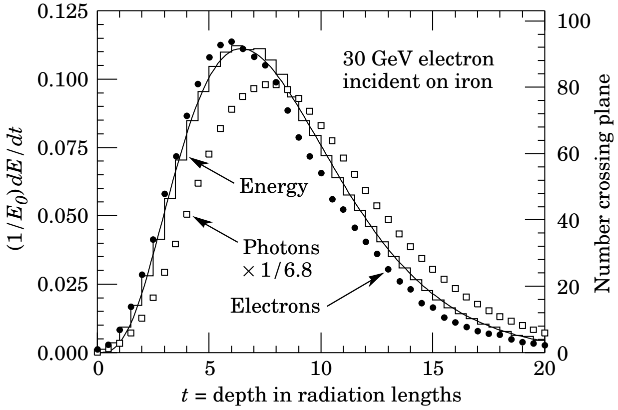


Figure 33.20: An EGS4 simulation of a 30 GeV electron-induced cascade in iron. The histogram shows fractional energy deposition per radiation length, and the curve is a gamma-function fit to the distribution.

33.6. Muon energy loss at high energy

At sufficiently high energies, radiative processes become more important than ionization for all charged particles. These contributions increase almost linearily with energy. It is convenient to write the average rate of muon energy loss as [72]

$$-dE/dx = a(E) + b(E)\,E \ . \tag{33.41}$$

Here $a(E)$ is the ionization energy loss given by Eq. (33.5), and $b(E)\,E$ is the sum of e^+e^- pair production, bremsstrahlung, and photonuclear contributions. These are subject large fluctuations, particularly at higher energies.

To the approximation that the slowly-varying functions $a(E)$ and $b(E)$ are constant, the mean range x_0 of a muon with initial energy E_0 is given by

$$x_0 \approx (1/b)\ln(1 + E_0/E_{\mu c}) \ , \tag{33.42}$$

where $E_{\mu c} = a/b$.

The "muon critical energy" $E_{\mu c}$ can be defined as the energy at which radiative and ionization losses are equal, and can be found by solving $E_{\mu c} = a(E_{\mu c})/b(E_{\mu c})$. This definition is different from the Rossi definition we used for electrons. It decreases with Z, and is several hundred GeV for iron. It is given for the elements and many other materials in `pdg.lbl.gov/AtomicNuclearProperties`.

33.7. Cherenkov and transition radiation

A charged particle radiates if its velocity is greater than the local phase velocity of light (Cherenkov radiation) or if it crosses suddenly from one medium to another with different optical properties (transition radiation). Neither process is important for energy loss, but both are used in high-energy and cosmic-ray physics detectors.

33.7.1. *Optical Cherenkov radiation* :

The angle θ_c of Cherenkov radiation, relative to the particle's direction, for a particle with velocity βc in a medium with index of refraction n is

$$\begin{aligned} \cos\theta_c &= (1/n\beta) \\ \text{or} \quad \tan\theta_c &= \sqrt{\beta^2 n^2 - 1} \\ &\approx \sqrt{2(1-1/n\beta)} \quad \text{for small } \theta_c, \textit{e.g.} \text{ in gases.} \end{aligned} \tag{33.43}$$

The threshold velocity β_t is $1/n$. Values of $n-1$ for various commonly used gases are given as a function of pressure and wavelength in Ref. 78. Data for other commonly used materials are given in Ref. 79.

The number of photons produced per unit path length of a particle with charge ze and per unit energy interval of the photons is

$$\begin{aligned} \frac{d^2N}{dEdx} &= \frac{\alpha z^2}{\hbar c}\sin^2\theta_c = \frac{\alpha^2 z^2}{r_e\, m_e c^2}\left(1 - \frac{1}{\beta^2 n^2(E)}\right) \\ &\approx 370 \sin^2\theta_c(E)\ \text{eV}^{-1}\text{cm}^{-1} \qquad (z=1)\ , \end{aligned} \tag{33.45}$$

or, equivalently,

$$\frac{d^2N}{dxd\lambda} = \frac{2\pi\alpha z^2}{\lambda^2}\left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right) \ . \tag{33.46}$$

33.7.2. *Coherent radio Cherenkov radiation* :

Coherent Cherenkov radiation is produced by many charged particles with a non-zero net charge moving through matter on an approximately common "wavefront"—for example, the electrons and positrons in a high-energy electromagnetic cascade. Near the end of a shower, when typical particle energies are below E_c (but still relativistic), a charge imbalance develops. Photons can Compton-scatter atomic electrons, and positrons can annihilate with atomic electrons to contribute even more photons which can in turn Compton scatter. These processes result in a roughly 20% excess of electrons over positrons in a shower. The net negative charge leads to coherent radio Cherenkov emission. The phenomenon is called the Askaryan effect [84]. The signals can be visible above backgrounds for shower energies as low as 10^{17} eV; see Sec. 35.3.3 for more details.

33.7.3. *Transition radiation* :

The energy radiated when a particle with charge ze crosses the boundary between vacuum and a medium with plasma frequency ω_p is

$$I = \alpha z^2 \gamma \hbar\omega_p/3 \ . \tag{33.47}$$

The plasma energy $\hbar\omega_p$ is defined in Table 33.1.

For styrene and similar materials, $\hbar\omega_p \approx 20$ eV; for air it is 0.7 eV. The number spectrum $dN_\gamma/d(\hbar\omega$ diverges logarithmically at low energies and decreases rapidly for $\hbar\omega/\gamma\hbar\omega_p > 1$. Inevitable absorption in a practical detector removes the divergence. About half the energy is emitted in the range $0.1 \le \hbar\omega/\gamma\hbar\omega_p \le 1$. The γ dependence of the emitted energy thus comes from the hardening of the spectrum rather than from an increased quantum yield. For a particle with $\gamma = 10^3$, the radiated photons are in the soft x-ray range 2 to 40 keV.

The number of photons with energy $\hbar\omega > \hbar\omega_0$ is given by the answer to problem 13.15 in Ref. 33,

$$N_\gamma(\hbar\omega > \hbar\omega_0) = \frac{\alpha z^2}{\pi}\left[\left(\ln\frac{\gamma\hbar\omega_p}{\hbar\omega_0} - 1\right)^2 + \frac{\pi^2}{12}\right] \ , \tag{33.49}$$

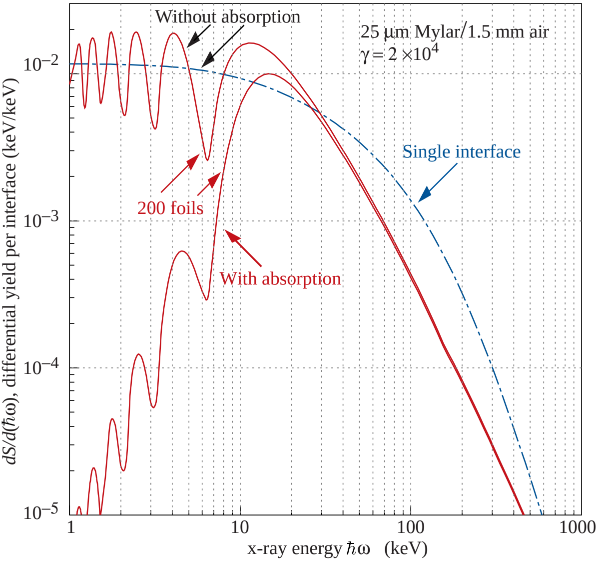


Figure 33.27: X-ray photon energy spectra for a radiator consisting of 200 25 μm thick foils of Mylar with 1.5 mm spacing in air (solid lines) and for a single surface (dashed line).

within corrections of order $(\hbar\omega_0/\gamma\hbar\omega_p)^2$. The number of photons above a fixed energy $\hbar\omega_0 \ll \gamma\hbar\omega_p$ thus grows as $(\ln\gamma)^2$, but the number above a fixed fraction of $\gamma\hbar\omega_p$ (as in the example above) is constant. For example, for $\hbar\omega > \gamma\hbar\omega_p/10$, $N_\gamma = 2.519\,\alpha z^2/\pi = 0.0059 \times z^2$.

The particle stays "in phase" with the x ray over a distance called the formation length, $d(\omega) = (2c/\omega)(1/\gamma^2 + \theta^2 + \omega_p^2/\omega^2)^{-1}$. Most of the radiation is produced in this distance. Here θ is the x-ray emission angle, characteristically $1/\gamma$. For $\theta = 1/\gamma$ the formation length has a maximum at $d(\gamma\omega_p/\sqrt{2}) = \gamma c/\sqrt{2}\,\omega_p$. In practical situations it is tens of μm.

Since the useful x-ray yield from a single interface is low, in practical detectors it is enhanced by using a stack of N foil radiators—foils L thick, where L is typically several formation lengths—separated by gas-filled gaps. The amplitudes at successive interfaces interfere to cause oscillations about the single-interface spectrum. At increasing frequencies above the position of the last interference maximum ($L/d(w) = \pi/2$), the formation zones, which have opposite phase, overlap more and more and the spectrum saturates, $dI/d\omega$ approaching zero as $L/d(\omega) \to 0$. This is illustrated in Fig. 33.27 for a realistic detector configuration.

Although one might expect the intensity of coherent radiation from the stack of foils to be proportional to N^2, the angular dependence of the formation length conspires to make the intensity $\propto N$.

34. Particle Detectors at Accelerators

34.1. Introduction

This review summarizes the detector technologies employed at accelerator particle physics experiments. Several of these detectors are also used in a non-accelerator context and examples of such applications will be provided. The detector techniques which are specific to non-accelerator particle physics experiments are the subject of Chap. 35. More detailed discussions of detectors and their underlying physics can be found in books by Ferbel [1], Kleinknecht [2], Knoll [3], Green [4], Leroy & Rancoita [5], and Grupen [6].

In Table 34.1 are given typical resolutions and deadtimes of common charged particle detectors. The quoted numbers are usually based on typical devices, and should be regarded only as rough approximations for new designs. The spatial resolution refers to the intrinsic detector resolution, i.e. without multiple scattering. We note that analog detector readout can provide better spatial resolution than digital readout by measuring the deposited charge in neighboring channels. Quoted ranges attempt to be representative of both possibilities. The time resolution is defined by how accurately the time at which a particle crossed the detector can be determined. The deadtime is the minimum separation in time between two resolved hits on the same channel. Typical performance of calorimetry and particle identification are provided in the relevant sections below.

Table 34.1: Typical resolutions and deadtimes of common charged particle detectors. Revised November 2011.

Detector Type	Intrinsinc Spatial Resolution (rms)	Time Resolution	Dead Time
Resistive plate chamber	$\lesssim 10$ mm	1 ns (50 ps^a)	—
Streamer chamber	300 μm^b	2 μs	100 ms
Liquid argon drift [7]	$\sim$175–450 μm	$\sim$ 200 ns	$\sim$ 2 μs
Scintillation tracker	$\sim$100 μm	100 ps/n^c	10 ns
Bubble chamber	10–150 μm	1 ms	50 ms^d
Proportional chamber	50–100 μm^e	2 ns	20-200 ns
Drift chamber	50–100 μm	2 ns^f	20-100 ns
Micro-pattern gas detectors	30–40 μm	$<$ 10 ns	10-100 ns
Silicon strip	pitch/(3 to 7)^g	few ns^h	$\lesssim 50$ ns^h
Silicon pixel	$\lesssim 10$ μm	few ns^h	$\lesssim 50$ ns^h
Emulsion	1 μm	—	—

[a] For multiple-gap RPCs.
[b] 300 μm is for 1 mm pitch (wirespacing/$\sqrt{12}$).
[c] n = index of refraction.
[d] Multiple pulsing time.
[e] Delay line cathode readout can give ± 150 μm parallel to anode wire.
[f] For two chambers.
[g] The highest resolution ("7") is obtained for small-pitch detectors ($\lesssim 25$ μm) with pulse-height-weighted center finding.
[h] Limited by the readout electronics [8].

Further discussion and all references may be found in the full *Review.*

36. Radioactivity and Radiation Protection

Revised October 2017 by S. Roesler and M. Silari (CERN).

36.1. Definitions

The International Commission on Radiation Units and Measurements (ICRU) recommends the use of SI units. Therefore we list SI units first, followed by cgs (or other common) units in parentheses, where they differ.

• **Activity** (unit: Becquerel):
1 Bq = 1 disintegration per second (= 27 pCi).

• **Absorbed dose** (unit: gray): The absorbed dose is the energy imparted by ionizing radiation in a volume element of a specified material divided by the mass of this volume element.

$$1 \text{ Gy} = 1 \text{ J/kg} \; (= 10^4 \text{ erg/g} = 100 \text{ rad})$$
$$= 6.24 \times 10^{12} \text{ MeV/kg deposited energy.}$$

• **Kerma** (unit: gray): Kerma is the sum of the initial kinetic energies of all charged particles liberated by indirectly ionizing particles in a volume element of the specified material divided by the mass of this volume element.

• **Exposure** (unit: C/kg of air [= 3880 Roentgen†]): The exposure is a measure of photon fluence at a certain point in space integrated over time, in terms of ion charge of either sign produced by secondary electrons in a small volume of air about the point. Implicit in the definition is the assumption that the small test volume is embedded in a sufficiently large uniformly irradiated volume that the number of secondary electrons entering the volume equals the number leaving (so-called charged particle equilibrium).

Table 36.1: Radiation weighting factors, w_R.

Radiation type	w_R
Photons	1
Electrons and muons	1
Neutrons, $E_n < 1$ MeV	$2.5 + 18.2 \times \exp[-(\ln E_n)^2/6]$
$1 \text{ MeV} \leq E_n \leq 50$ MeV	$5.0 + 17.0 \times \exp[-(\ln(2E_n))^2/6]$
$E_n > 50$ MeV	$2.5 + 3.25 \times \exp[-(\ln(0.04E_n))^2/6]$
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20

• **Equivalent dose** (unit: Sievert [= 100 rem (roentgen equivalent in man)]): The equivalent dose H_T in an organ or tissue T is equal to the sum of the absorbed doses $D_{T,R}$ in the organ or tissue caused by different radiation types R weighted with so-called radiation weighting factors w_R:

$$H_T = \sum_R w_R \times D_{T,R} \; . \tag{36.1}$$

† This unit is somewhat historical, but appears on some measuring instruments. One R is the amount of radiation required to liberate positive and negative charges of one electrostatic unit of charge in 1 cm^3 of air at standard temperature and pressure (STP)

It expresses long-term risks (primarily cancer and leukemia) from low-level chronic exposure. The values for w_R recommended recently by ICRP [2] are given in Table 36.1.

• **Effective dose** (unit: Sievert): The sum of the equivalent doses, weighted by the tissue weighting factors w_T ($\sum_T w_T = 1$) of several organs and tissues T of the body that are considered to be most sensitive [2], is called "effective dose" E:

$$E = \sum_T w_T \times H_T \ . \tag{36.2}$$

36.2. Radiation levels [4]

• **Natural annual background**, all sources: Most world areas, whole-body equivalent dose rate $\approx$ (1.0–13) mSv (0.1–1.3 rem). Can range up to 50 mSv (5 rem) in certain areas. U.S. average $\approx$ 3.6 mSv, including $\approx$ 2 mSv ($\approx$ 200 mrem) from inhaled natural radioactivity, mostly radon and radon daughters. (Average is for a typical house and varies by more than an order of magnitude. It can be more than two orders of magnitude higher in poorly ventilated mines. 0.1–0.2 mSv in open areas.)

• **Cosmic ray background** (sea level, mostly muons):
~ 1 min^{-1} cm^{-2} sr^{-1}. For more accurate estimates and details, see the Cosmic Rays section (Sec. 29 of this *Review*).

• **Fluence** (per cm^2) to deposit one Gy, assuming uniform irradiation:

$\approx$ (**charged particles**) $6.24{\times}10^9/(dE/dx)$, where dE/dx (MeV g^{-1} cm^2), the energy loss per unit length, may be obtained from Figs. 33.2 and 33.4 in Sec. 33 of the *Review*, and `pdg.lbl.gov/AtomicNuclearProperties`.

$\approx 3.5 \times 10^9$ cm^{-2} minimum-ionizing singly-charged particles in carbon.

$\approx$ (**photons**) $6.24{\times}10^9/[Ef/\ell]$, for photons of energy E (MeV), attenuation length ℓ (g cm^{-2}), and fraction $f \lesssim 1$ expressing the fraction of the photon's energy deposited in a small volume of thickness $\ll \ell$ but large enough to contain the secondary electrons.

$\approx 2 \times 10^{11}$ photons cm^{-2} for 1 MeV photons on carbon ($f \approx 1/2$).

36.3. Health effects of ionizing radiation

• **Recommended limits of effective dose to radiation workers (whole-body dose):***

EU/Switzerland: 20 mSv yr^{-1}

U.S.: 50 mSv yr^{-1} (5 rem yr^{-1})†

• **Lethal dose**: The whole-body dose from penetrating ionizing radiation resulting in 50% mortality in 30 days (assuming no medical treatment) is 2.5–4.5 Gy (250–450 rad), as measured internally on body longitudinal center line. Surface dose varies due to variable body attenuation and may be a strong function of energy.

• **Cancer induction by low LET radiation**: The cancer induction probability is about 5% per Sv on average for the entire population [2].

Footnotes:

* The ICRP recommendation [2] is 20 mSv yr^{-1} averaged over 5 years, with the dose in any one year $\leq$ 50 mSv.

† Many laboratories in the U.S. and elsewhere set lower limits.

See full *Review* for references and further details.

37. Commonly Used Radioactive Sources

Table 37.1. Revised August 2017 by D.E. Groom (LBNL) and R.B. Firestone (LBNL).

			Particle		Photon	
Nuclide	Half-life	Type of decay	Energy (MeV)	Emission prob.	Energy (MeV)	Emission prob.
$^{22}_{11}$Na	2.603 y	β^+, EC	0.546	90%	0.511 1.275	Annih. 100%
$^{51}_{24}$Cr	27.70 d	EC			0.340 V K x rays	10% 100%
			Neutrino calibration source			
$^{54}_{25}$Mn	0.855 y	EC			0.835 Cr K x rays	100% 26%
$^{55}_{26}$Fe	2.747 y	EC			Mn K x rays: 0.00590 0.00649	 24.4% 2.86%
$^{57}_{27}$Co	271.8 d	EC			0.014 0.122 0.136 Fe K x rays	9% 86% 11% 58%
$^{60}_{27}$Co	5.271 y	β^-	0.317	99.9%	1.173 1.333	99.9% 99.9%
$^{68}_{32}$Ge	271.0 d	EC			Ga K x rays	42%
$\rightarrow$ $^{68}_{31}$Ga	67.8 m	β^+, EC	1.899	90%	0.511 1.077	Annih. 3%
$^{90}_{38}$Sr	28.8 y	β^-	0.546	100%		
$\rightarrow$ $^{90}_{39}$Y	2.67 d	β^-	2.279	100%		
$^{106}_{44}$Ru	371.5 d	β^-	0.039	100%		
$\rightarrow$ $^{106}_{45}$Rh	30.1 s	β^-	3.546	79%	0.512 0.622	21% 10%
$^{109}_{48}$Cd	1.265 y	EC	0.063 e^- 0.084 e^-	42% 44%	0.088 Ag K x rays	3.7% 100%
$^{113}_{50}$Sn	115.1 d	EC	0.364 e^- 0.388 e^-	28% 6%	0.392 In K x rays	65% 97%
$^{137}_{55}$Cs	30.0 y	β^-	0.514 1.176	94% 6%	0.662	85%

$^{133}_{56}$Ba	10.55 y	EC	0.045 e^-	50%	0.081	33%
			0.075 e^-	6%	0.356	62%
					Cs K x rays 121%	
$^{152}_{63}$Eu	13.537 y	EC		72.1%	Many γ's	
		β^-		27.9%	0.1218–1.408 MeV	
$^{207}_{83}$Bi	32.9 y	EC	0.481 e^-	2%	0.569	98%
			0.975 e^-	7%	1.063	75%
			1.047 e^-	2%	1.770	7%
					Pb K x rays 78%	
$^{228}_{90}$Th	1.912 y	6α:	5.341 to 8.785		0.239	44%
		$3\beta^-$:	0.334 to 2.246		0.583	31%
					2.614	36%
(→$^{224}_{88}$Ra	→ $^{220}_{86}$Rn	→ $^{216}_{84}$Po	→ $^{212}_{82}$Pb	→ $^{212}_{83}$Bi	→ $^{212}_{84}$Po)	
(361 d	55.8 s	0.148 s	10.64 h	60.54 m	300 ns)	
$^{241}_{95}$Am	432.6 y	α	5.443	13%	0.060	36%
			5.486	84%	Np L x rays 38%	
$^{241}_{95}$Am/Be	432.6 y	6×10^{-5} neutrons ($\langle E \rangle = 4$ MeV) and 4×10^{-5} γ's (4.43 MeV from $^9_4$Be(α, n))				
$^{244}_{96}$Cm	18.11 y	α	5.763	24%	Pu L x rays $\sim 9\%$	
			5.805	76%		
$^{252}_{98}$Cf	2.645 y	α (97%)	6.076	15%		
			6.118	82%		
	Fission (3.1%): Average 7.8 γ's/fission; $\langle E_\gamma \rangle = 0.88$ MeV; ≈ 4 neutrons/fission; $\langle E_n \rangle = 2.14$ MeV					

"Emission probability" is the probability per decay of a given emission; because of cascades these may total more than 100%. Only principal emissions are listed. EC means electron capture, and e^- means monoenergetic internal conversion (Auger) electron. The intensity of 0.511 MeV e^+e^- annihilation photons depends upon the number of stopped positrons. Endpoint $\beta^\pm$ energies are listed. In some cases when energies are closely spaced, the γ-ray values are approximate weighted averages. Radiation from short-lived daughter isotopes is included where relevant.

Half-lives, energies, and intensities may be found in `www-pub.iaea.org/books/IAEABooks/7551/Update-of-X-Ray-and-Gamma-Ray-Decay-Data-Standards-for-Detector-Calibration-and-Other-Applications`, `IAEA` (2007) or Nuclear Data Sheets (`www.journals.elsevier.com/nuclear-data-sheets`) (2007).
Neutron sources: See *e.g.* "Neutron Calibration Sources in the Daya Bay Experiment," J. Liu *et al.*, Nuclear Instrum. Methods **A797,** 260 (2005) (arXiv.1504.07911).

$^{51}_{24}$Cr calibration of neutrino detectors is discussed in *e.g.* J.N. Abdurashitov *et al.* [SAGE Collaboration], Phys. Rev. **C59**, 2246 (1999). The use of $^{75}_{34}$Se and other isotopes has been proposed.

38. PROBABILITY

Revised September 2015 by G. Cowan (RHUL).

The following is a much-shortened version of Sec. 38 of the full *Review*. Equation, section, and figure numbers follow the *Review*.

38.2. Random variables

• *Probability density function* (p.d.f.): x is a *random variable*.

Continuous: $f(x;\theta)dx$ = probability x is between x to $x+dx$, given parameter(s) θ;

Discrete: $f(x;\theta)$ = probability of x given θ.

• *Cumulative distribution function*:

$$F(a) = \int_{-\infty}^{a} f(x)\, dx \ . \tag{38.6}$$

Here and below, if x is discrete-valued, the integral is replaced by a sum. The endpoint a is indcluded in the integral or sum.

• *Expectation values*: Given a function u:

$$E\left[u(x)\right] = \int_{-\infty}^{\infty} u(x)\, f(x)\, dx \ . \tag{38.7}$$

• *Moments*:

$$n\text{th moment of a random variable: } \alpha_n = E[x^n] \ , \tag{38.8a}$$

$$n\text{th central moment: } m_n = E[(x-\alpha_1)^n] \ . \tag{38.8b}$$

$$\text{Mean: } \mu \equiv \alpha_1 \ . \tag{38.9a}$$

$$\text{Variance: } \sigma^2 \equiv V[x] \equiv m_2 = \alpha_2 - \mu^2 \ . \tag{38.9b}$$

Coefficient of skewness: $\gamma_1 \equiv m_3/\sigma^3$.
Kurtosis: $\gamma_2 = m_4/\sigma^4 - 3$.
Median: $F(x_{\text{med}}) = 1/2$.

• *Marginal* p.d.f.: Let x,y be two random variables with joint p.d.f. $f(x,y)$.

$$f_1(x) = \int_{-\infty}^{\infty} f(x,y)\, dy \ ; \qquad f_2(y) = \int_{-\infty}^{\infty} f(x,y)\, dx \ . \tag{38.10}$$

• *Conditional* p.d.f.:

$$f_4(x|y) = f(x,y)/f_2(y) \ ; \quad f_3(y|x) = f(x,y)/f_1(x) \ .$$

• *Bayes' theorem*:

$$f_4(x|y) = \frac{f_3(y|x)f_1(x)}{f_2(y)} = \frac{f_3(y|x)f_1(x)}{\int f_3(y|x')f_1(x')\, dx'} \ . \tag{38.11}$$

• *Correlation coefficient and covariance*:

$$\mu_x = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x f(x,y)\, dx\, dy \ , \tag{38.12}$$

$$\rho_{xy} = E\left[(x-\mu_x)(y-\mu_y)\right]/\sigma_x\,\sigma_y \equiv \text{cov}[x,y]/\sigma_x\,\sigma_y \ ,$$

$$\sigma_x = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} (x-\mu_x)^2 \, f(x,y)\, dx\, dy \; . \;\; \text{Note } \rho_{xy}^2 \leq 1.$$

• *Independence*: x,y are independent if and only if $f(x,y) = f_1(x) \cdot f_2(y)$; then $\rho_{xy} = 0$, $E[u(x)\, v(y)] = E[u(x)]\, E[v(y)]$ and $V[x+y] = V[x]+V[y]$.

• *Change of variables*: From $\boldsymbol{x} = (x_1, \ldots, x_n)$ to $\boldsymbol{y} = (y_1, \ldots, y_n)$: $g(\boldsymbol{y}) = f(\boldsymbol{x}(\boldsymbol{y})) \cdot |J|$ where $|J|$ is the absolute value of the determinant of the Jacobian $J_{ij} = \partial x_i / \partial y_j$. For discrete variables, use $|J| = 1$.

38.3. Characteristic functions

Given a pdf $f(x)$ for a continuous random variable x, the characteristic function $\phi(u)$ is given by (31.6). Its derivatives are related to the algebraic moments of x by (31.7).

$$\phi(u) = E\left[e^{iux}\right] = \int_{-\infty}^{\infty} e^{iux} f(x)\, dx \; . \tag{38.17}$$

$$i^{-n} \left. \frac{d^n \phi}{du^n} \right|_{u=0} = \int_{-\infty}^{\infty} x^n f(x)\, dx = \alpha_n \; . \tag{38.18}$$

If the p.d.f.s $f_1(x)$ and $f_2(y)$ for independent random variables x and y have characteristic functions $\phi_1(u)$ and $\phi_2(u)$, then the characteristic function of the weighted sum $ax + by$ is $\phi_1(au)\phi_2(bu)$. The additional rules for several important distributions (*e.g.*, that the sum of two Gaussian distributed variables also follows a Gaussian distribution) easily follow from this observation.

38.4. Some probability distributions

See Table 38.1.

38.4.2. *Poisson distribution* :

The Poisson distribution $f(n;\nu)$ gives the probability of finding exactly n events in a given interval of x (*e.g.*, space or time) when the events occur independently of one another and of x at an average rate of ν per the given interval. The variance σ^2 equals ν. It is the limiting case $p \to 0$, $N \to \infty$, $Np = \nu$ of the binomial distribution. The Poisson distribution approaches the Gaussian distribution for large ν.

38.4.3. *Normal or Gaussian distribution* :

Its cumulative distribution, for mean 0 and variance 1, is often tabulated as the *error function*

$$F(x;0,1) = \tfrac{1}{2}\left[1 + \operatorname{erf}(x/\sqrt{2})\right] \; . \tag{38.24}$$

For mean μ and variance σ^2, replace x by $(x-\mu)/\sigma$.
$P(x \text{ in range } \mu \pm \sigma) = 0.6827$,
$P(x \text{ in range } \mu \pm 0.6745\sigma) = 0.5$,
$E[|x-\mu|] = \sqrt{2/\pi}\sigma = 0.7979\sigma$,
half-width at half maximum $= \sqrt{2\ln 2} \cdot \sigma = 1.177\sigma$.

Table 38.1. Some common probability density functions, with corresponding characteristic functions and means and variances. In the Table, $\Gamma(k)$ is the gamma function, equal to $(k-1)!$ when k is an integer.

Distribution	Probability density function f (variable; parameters)	Characteristic function $\phi(u)$	Mean	Variance σ^2
Uniform	$f(x;a,b) = \begin{cases} 1/(b-a) & a \le x \le b \\ 0 & \text{otherwise} \end{cases}$	$\dfrac{e^{ibu} - e^{iau}}{(b-a)iu}$	$\dfrac{a+b}{2}$	$\dfrac{(b-a)^2}{12}$
Binomial	$f(r;N,p) = \dfrac{N!}{r!(N-r)!}\; p^r q^{N-r}$ $r = 0,1,2,\ldots,N\,; \quad 0 \le p \le 1\,; \quad q = 1-p$	$(q + pe^{iu})^N$	Np	Npq
Poisson	$f(n;\nu) = \dfrac{\nu^n e^{-\nu}}{n!}\,; \quad n = 0,1,2,\ldots\,; \quad \nu > 0$	$\exp[\nu(e^{iu} - 1)]$	ν	ν
Normal (Gaussian)	$f(x;\mu,\sigma^2) = \dfrac{1}{\sigma\sqrt{2\pi}}\; \exp(-(x-\mu)^2/2\sigma^2)$ $-\infty < x < \infty\,; \quad -\infty < \mu < \infty\,; \quad \sigma > 0$	$\exp(i\mu u - \frac{1}{2}\sigma^2 u^2)$	μ	σ^2
Multivariate Gaussian	$f(\boldsymbol{x};\boldsymbol{\mu},V) = \dfrac{1}{(2\pi)^{n/2}\sqrt{\lvert V\rvert}}$ $\times \exp\left[-\frac{1}{2}(\boldsymbol{x}-\boldsymbol{\mu})^T V^{-1}(\boldsymbol{x}-\boldsymbol{\mu})\right]$ $-\infty < x_j < \infty; \quad -\infty < \mu_j < \infty; \quad \lvert V\rvert > 0$	$\exp\left[i\boldsymbol{\mu}\cdot\boldsymbol{u} - \frac{1}{2}\boldsymbol{u}^T V \boldsymbol{u}\right]$	$\boldsymbol{\mu}$	V_{jk}
χ^2	$f(z;n) = \dfrac{z^{n/2-1}e^{-z/2}}{2^{n/2}\Gamma(n/2)}\,; \quad z \ge 0$	$(1-2iu)^{-n/2}$	n	$2n$
Student's t	$f(t;n) = \dfrac{1}{\sqrt{n\pi}}\,\dfrac{\Gamma[(n+1)/2]}{\Gamma(n/2)}\left(1 + \dfrac{t^2}{n}\right)^{-(n+1)/2}$ $-\infty < t < \infty\,; \quad n$ not required to be integer	—	0 for $n > 1$	$n/(n-2)$ for $n > 2$
Gamma	$f(x;\lambda,k) = \dfrac{x^{k-1}\lambda^k e^{-\lambda x}}{\Gamma(k)}\,; \quad 0 \le x < \infty\,;$ k not required to be integer	$(1 - iu/\lambda)^{-k}$	k/λ	k/λ^2

For n Gaussian random variables $\boldsymbol{x}_i$, the joint p.d.f. is the multivariate Gaussian:

$$f(\boldsymbol{x};\boldsymbol{\mu},V)=\frac{1}{(2\pi)^{n/2}\sqrt{|V|}}\exp\left[-\tfrac{1}{2}(\boldsymbol{x}-\boldsymbol{\mu})^T V^{-1}(\boldsymbol{x}-\boldsymbol{\mu})\right],\ |V|>0\,. \tag{38.25}$$

V is the $n\times n$ *covariance matrix*; $V_{ij}\equiv E[(x_i-\mu_i)(x_j-\mu_j)]\equiv\rho_{ij}\,\sigma_i\,\sigma_j$, and $V_{ii}=V[x_i]$; $|V|$ is the determinant of V. For $n=2$, $f(\boldsymbol{x};\boldsymbol{\mu},V)$ is

$$f(x_1,x_2;\ \mu_1,\mu_2,\sigma_1,\sigma_2,\rho)=\frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}}\times\ \exp\left\{\frac{-1}{2(1-\rho^2)}\right.$$

$$\left.\left[\frac{(x_1-\mu_1)^2}{\sigma_1^2}-\frac{2\rho(x_1-\mu_1)(x_2-\mu_2)}{\sigma_1\sigma_2}+\frac{(x_2-\mu_2)^2}{\sigma_2^2}\right]\right\}. \tag{38.26}$$

The marginal distribution of any x_i is a Gaussian with mean μ_i and variance V_{ii}. V is $n\times n$, symmetric, and positive definite. Therefore for any vector $\boldsymbol{X}$, the quadratic form $\boldsymbol{X}^T V^{-1}\boldsymbol{X}=C$, where C is any positive number, traces an n-dimensional ellipsoid as $\boldsymbol{X}$ varies. If $X_i=x_i-\mu_i$, then C is a random variable obeying the χ^2 distribution with n degrees of freedom, discussed in the following section. The probability that $\boldsymbol{X}$ corresponding to a set of Gaussian random variables x_i lies outside the ellipsoid characterized by a given value of C ($=\chi^2$) is given by $1-F_{\chi^2}(C;n)$, where F_{χ^2} is the cumulative χ^2 distribution. This may be read from Fig. 39.1. For example, the "s-standard-deviation ellipsoid" occurs at $C=s^2$. For the two-variable case ($n=2$), the point $\boldsymbol{X}$ lies outside the one-standard-deviation ellipsoid with 61% probability. The use of these ellipsoids as indicators of probable error is described in Sec. 39.4.2.2; the validity of those indicators assumes that $\boldsymbol{\mu}$ and V are correct.

38.4.5. χ^2 *distribution* :

If $x_1,\ldots,x_n$ are independent Gaussian random variables, the sum $z=\sum_{i=1}^n(x_i-\mu_i)^2/\sigma_i^2$ follows the χ^2 p.d.f. with n *degrees of freedom*, which we denote by $\chi^2(n)$. More generally, for n correlated Gaussian variables as components of a vector $\boldsymbol{X}$ with covariance matrix V, $z=\boldsymbol{X}^T V^{-1}\boldsymbol{X}$ follows $\chi^2(n)$ as in the previous section. For a set of z_i, each of which follows $\chi^2(n_i)$, $\sum z_i$ follows $\chi^2(\sum n_i)$. For large n, the χ^2 p.d.f. approaches a Gaussian with mean $\mu=n$ and variance $\sigma^2=2n$.
The χ^2 p.d.f. is often used in evaluating the level of compatibility between observed data and a hypothesis for the p.d.f. that the data might follow. This is discussed further in Sec. 39.3.2 on tests of goodness-of-fit.

38.4.7. *Gamma distribution* :

For a process that generates events as a function of x (*e.g.*, space or time) according to a Poisson distribution, the distance in x from an arbitrary starting point (which may be some particular event) to the k^{th} event follows a *gamma* distribution, $f(x;\lambda,k)$. The Poisson parameter μ is λ per unit x. The special case $k=1$ (*i.e.*, $f(x;\lambda,1)=\lambda e^{-\lambda x}$) is called the *exponential* distribution. A sum of k' exponential random variables x_i is distributed as $f(\sum x_i;\lambda,k')$.
The parameter k is not required to be an integer. For $\lambda=1/2$ and $k=n/2$, the gamma distribution reduces to the $\chi^2(n)$ distribution.

See the full *Review* for further discussion and all references.

39. Statistics

Revised September 2017 by G. Cowan (RHUL).

This chapter gives an overview of statistical methods used in high-energy physics. In statistics, we are interested in using a given sample of data to make inferences about a probabilistic model, *e.g.*, to assess the model's validity or to determine the values of its parameters. There are two main approaches to statistical inference, which we may call frequentist and Bayesian.

39.2. Parameter estimation

An *estimator* $\widehat{\theta}$ (written with a hat) is a function of the data used to estimate the value of the parameter θ.

39.2.1. *Estimators for mean, variance, and median* :

Suppose we have a set of n independent measurements, $x_1, \ldots, x_n$, each assumed to follow a p.d.f. with unknown mean μ and unknown variance σ^2 (the measurements do not necessarily have to follow a Gaussian distribution). Then

$$\widehat{\mu} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{39.5}$$

$$\widehat{\sigma^2} = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \widehat{\mu})^2 \tag{39.6}$$

are unbiased estimators of μ and σ^2. The variance of $\widehat{\mu}$ is σ^2/n and the variance of $\widehat{\sigma^2}$ is

$$V\left[\widehat{\sigma^2}\right] = \frac{1}{n}\left(m_4 - \frac{n-3}{n-1}\sigma^4\right) , \tag{39.7}$$

where m_4 is the 4^{th} central moment of x (see Eq. (38.8b)). For Gaussian distributed x_i, this becomes $2\sigma^4/(n-1)$ for any $n \geq 2$, and for large n the standard deviation of $\widehat{\sigma}$ is $\sigma/\sqrt{2n}$.

If the x_i have different, known variances σ_i^2, then the weighted average

$$\widehat{\mu} = \frac{1}{w}\sum_{i=1}^{n} w_i x_i , \tag{39.8}$$

where $w_i = 1/\sigma_i^2$ and $w = \sum_i w_i$, is an unbiased estimator for μ with a smaller variance than an unweighted average. The standard deviation of $\widehat{\mu}$ is $1/\sqrt{w}$.

39.2.2. *The method of maximum likelihood* :

Suppose we have a set of measured quantities $\boldsymbol{x}$ and the likelihood $L(\boldsymbol{\theta}) = P(\boldsymbol{x}|\boldsymbol{\theta})$ for a set of parameters $\boldsymbol{\theta} = (\theta_1, \ldots, \theta_N)$. The *maximum likelihood* (ML) estimators for $\boldsymbol{\theta}$ can be found by solving the *likelihood equations*,

$$\frac{\partial \ln L}{\partial \theta_i} = 0 , \qquad i = 1, \ldots, N . \tag{39.9}$$

In the large sample limit, the s times the standard deviations σ_i of the estimators for the parameters can be obtained from the hypersurface defined by the $\boldsymbol{\theta}$ such that

$$\ln L(\boldsymbol{\theta}) = \ln L_{\max} - s^2/2 , \tag{39.10}$$

39.2.3. *The method of least squares* :

For Gaussian distributed measurements y_i with mean $\mu(x_i;\boldsymbol{\theta})$ and known variance σ_i^2, the log-likelihood function contains the sum of squares

$$\chi^2(\boldsymbol{\theta}) = -2\ln L(\boldsymbol{\theta}) + \text{ constant } = \sum_{i=1}^{N} \frac{(y_i - \mu(x_i;\boldsymbol{\theta}))^2}{\sigma_i^2} \ . \tag{39.19}$$

If the y_i have a covariance matrix $V_{ij} = \mathrm{cov}[y_i, y_j]$, then the estimators are determined by the minimum of

$$\chi^2(\boldsymbol{\theta}) = (\boldsymbol{y} - \boldsymbol{\mu}(\boldsymbol{\theta}))^T V^{-1} (\boldsymbol{y} - \boldsymbol{\mu}(\boldsymbol{\theta})) \ , \tag{39.20}$$

39.3. Statistical tests

39.3.1. *Hypothesis tests* :

A frequentist *test* of a hypothesis (often called the null hypothesis, H_0) is a rule that states for which data values $\boldsymbol{x}$ the hypothesis is rejected. A critical region w is specified such that there is no more than a given probability α, called the *size* or *significance level* of the test, to find $\boldsymbol{x} \in w$. If the data are discrete, it may not be possible to find a critical region with exact probability content α, and thus we require $P(\boldsymbol{x} \in w|H_0) \leq \alpha$. If the data are observed in the critical region, H_0 is rejected.

The critical region is not unique, and generally defined relative to some alternative hypothesis (or set of alternatives) H_1. To maximize the power of the test of H_0 with respect to the alternative H_1, the *Neyman–Pearson lemma* states that the critical region w should be chosen such that for all data values $\boldsymbol{x}$ inside w, the likelihood ratio

$$\lambda(\boldsymbol{x}) = \frac{f(\boldsymbol{x}|H_1)}{f(\boldsymbol{x}|H_0)} \tag{39.44}$$

is greater than or equal to a given constant c_α, and everywhere outside the critical region one has $\lambda(\boldsymbol{x}) < c_\alpha$, where the value of c_α is determined by the size of the test α. Here H_0 and H_1 must be simple hypotheses, *i.e.*, they should not contain undetermined parameters.

39.3.2. *Tests of significance (goodness-of-fit)* :

Often one wants to quantify the level of agreement between the data and a hypothesis without explicit reference to alternative hypotheses. This can be done by defining a statistic t whose value reflects in some way the level of agreement between the data and the hypothesis. For example, if t is defined such that large values correspond to poor agreement with the hypothesis, then the p-value would be

$$p = \int_{t_{\mathrm{obs}}}^{\infty} f(t|H_0)\, dt \ , \tag{39.45}$$

where t_{obs} is the value of the statistic obtained in the actual experiment.

39.3.2.1. *Goodness-of-fit with the method of least squares:*

For Poisson measurements n_i with variances $\sigma_i^2 = \mu_i$, the χ^2 (39.19) becomes *Pearson's* χ^2 *statistic*,

$$\chi^2 = \sum_{i=1}^{N} \frac{(n_i - \mu_i)^2}{\mu_i} \ . \tag{39.53}$$

Assuming the goodness-of-fit statistic follows a χ^2 p.d.f., the p-value for the hypothesis is then

$$p = \int_{\chi^2}^{\infty} f(z; n_{\mathrm{d}})\, dz \ , \tag{39.54}$$

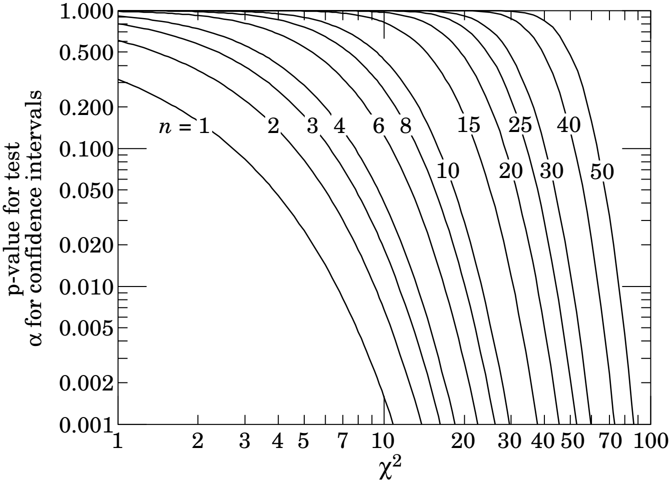


Figure 39.1: One minus the χ^2 cumulative distribution, $1-F(\chi^2;n)$, for n degrees of freedom. This gives the p-value for the χ^2 goodness-of-fit test as well as one minus the coverage probability for confidence regions (see Sec. 39.4.2.2).

where $f(z;n_{\rm d})$ is the χ^2 p.d.f. and $n_{\rm d}$ is the appropriate number of degrees of freedom. Values are shown in Fig. 39.1. The p-values obtained for different values of $\chi^2/n_{\rm d}$ are shown in Fig. 39.2.

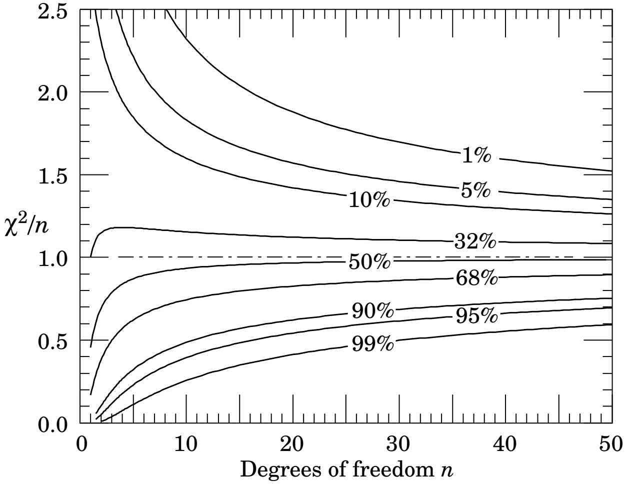


Figure 39.2: The 'reduced' χ^2, equal to χ^2/n, for n degrees of freedom. The curves show as a function of n the χ^2/n that corresponds to a given p-value.

39.3.3. *Bayes factors* :

In Bayesian statistics, one could reject a hypothesis H if its posterior probability $P(H|\boldsymbol{x})$ is sufficiently small. The full prior probability for two models (hypotheses) H_i and H_j can be written in the form

$$\pi(H_i, \boldsymbol{\theta}_i) = P(H_i)\pi(\boldsymbol{\theta}_i|H_i) \ . \tag{39.55}$$

The *Bayes factor* is defined as

$$B_{ij} = \frac{\int P(\boldsymbol{x}|\boldsymbol{\theta}_i, H_i)\pi(\boldsymbol{\theta}_i|H_i)\, d\boldsymbol{\theta}_i}{\int P(\boldsymbol{x}|\boldsymbol{\theta}_j, H_j)\pi(\boldsymbol{\theta}_j|H_j)\, d\boldsymbol{\theta}_j} \ . \tag{39.58}$$

This gives what the ratio of posterior probabilities for models i and j would be if the overall prior probabilities for the two models were equal.

39.4. Intervals and limits

39.4.1. *Bayesian intervals* :

A Bayesian or credible interval) $[\theta_{\rm lo}, \theta_{\rm up}]$ can be determined which contains a given fraction $1-\alpha$ of the posterior probability, *i.e.*,

$$1 - \alpha = \int_{\theta_{\rm lo}}^{\theta_{\rm up}} p(\theta|\boldsymbol{x})\, d\theta \ . \tag{39.60}$$

39.4.2. *Frequentist confidence intervals* :

39.4.2.1. *The Neyman construction for confidence intervals:*

Given a p.d.f. $f(x;\theta)$, we can find using a pre-defined rule and probability $1-\alpha$ for every value of θ, a set of values $x_1(\theta,\alpha)$ and $x_2(\theta,\alpha)$ such that

$$P(x_1 < x < x_2; \theta) = \int_{x_1}^{x_2} f(x;\theta)\, dx \geq 1 - \alpha \ . \tag{39.67}$$

39.4.2.2. *Gaussian distributed measurements:*

When the data consists of a single random variable x that follows a Gaussian distribution with known σ, the probability that the measured value x will fall within $\pm\delta$ of the true value μ is

$$1 - \alpha = \frac{1}{\sqrt{2\pi}\sigma} \int_{\mu-\delta}^{\mu+\delta} e^{-(x-\mu)^2/2\sigma^2}\, dx = \text{erf}\left(\frac{\delta}{\sqrt{2}\,\sigma}\right) = 2\Phi\left(\frac{\delta}{\sigma}\right) - 1 \ , \tag{39.70}$$

Fig. 39.4 shows a $\delta = 1.64\sigma$ confidence interval unshaded. Values of α for other frequently used choices of δ are given in Table 39.1.

Table 39.1: Area of the tails α outside $\pm\delta$ from the mean of a Gaussian distribution.

α	δ	α	δ
0.3173	1σ	0.2	1.28σ
4.55×10^{-2}	2σ	0.1	1.64σ
2.7×10^{-3}	3σ	0.05	1.96σ
6.3×10^{-5}	4σ	0.01	2.58σ
5.7×10^{-7}	5σ	0.001	3.29σ
2.0×10^{-9}	6σ	10^{-4}	3.89σ

We can set a one-sided (upper or lower) limit by excluding above $x+\delta$ (or below $x-\delta$). The values of α for such limits are half the values in Table 39.1. Values of $\Delta\chi^2$ or $2\Delta\ln L$ are given in Table 39.2 for several values of the coverage probability $1-\alpha$ and number of fitted parameters m.

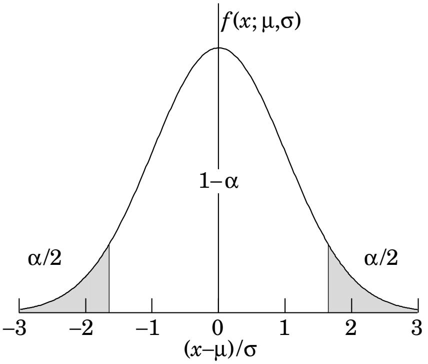


Figure 39.4: Illustration of a symmetric 90% confidence interval (unshaded) for a Gaussian-distributed measurement of a single quantity. Integrated probabilities, defined by $\alpha = 0.1$, are as shown.

Table 39.2: Values of $\Delta\chi^2$ or $2\Delta \ln L$ corresponding to a coverage probability $1-\alpha$ in the large data sample limit, for joint estimation of m parameters.

$(1-\alpha)$ (%)	$m = 1$	$m = 2$	$m = 3$
68.27	1.00	2.30	3.53
90.	2.71	4.61	6.25
95.	3.84	5.99	7.82
95.45	4.00	6.18	8.03
99.	6.63	9.21	11.34
99.73	9.00	11.83	14.16

39.4.2.3. *Poisson or binomial data:*

For Poisson distributed n, the upper and lower limits on the mean value μ from the Neyman procedure are

$$\mu_{\mathrm{lo}} = \tfrac{1}{2} F^{-1}_{\chi^2}(\alpha_{\mathrm{lo}}; 2n) \ , \tag{39.76a}$$

$$\mu_{\mathrm{up}} = \tfrac{1}{2} F^{-1}_{\chi^2}(1-\alpha_{\mathrm{up}}; 2(n+1)) \ , \tag{39.76b}$$

For the case of binomially distributed n successes out of N trials with probability of success p, the upper and lower limits on p are found to be

$$p_{\mathrm{lo}} = \frac{nF_F^{-1}[\alpha_{\mathrm{lo}}; 2n, 2(N-n+1)]}{N-n+1\ +\ nF_F^{-1}[\alpha_{\mathrm{lo}}; 2n, 2(N-n+1)]} \ , \tag{39.77a}$$

$$p_{\mathrm{up}} = \frac{(n+1)F_F^{-1}[1-\alpha_{\mathrm{up}}; 2(n+1), 2(N-n)]}{(N-n)\ +\ (n+1)F_F^{-1}[1-\alpha_{\mathrm{up}}; 2(n+1), 2(N-n)]} \ . \tag{39.77b}$$

Here F_F^{-1} is the quantile of the F distribution (also called the Fisher–Snedecor distribution; see Ref. [4]) .

Several problems with such intervals are overcome by using the unified approach of Feldman and Cousins [38]. Properties of these intervals are described further in the *Review*. Table 39.4 gives the unified confidence intervals $[\mu_1, \mu_2]$ for the mean of a Poisson variable given n observed

Table 39.3: Lower and upper (one-sided) limits for the mean μ of a Poisson variable given n observed events in the absence of background, for confidence levels of 90% and 95%.

	$1-\alpha$ =90%		$1-\alpha$ =95%	
n	$\mu_{\rm lo}$	$\mu_{\rm up}$	$\mu_{\rm lo}$	$\mu_{\rm up}$
0	–	2.30	–	3.00
1	0.105	3.89	0.051	4.74
2	0.532	5.32	0.355	6.30
3	1.10	6.68	0.818	7.75
4	1.74	7.99	1.37	9.15
5	2.43	9.27	1.97	10.51
6	3.15	10.53	2.61	11.84
7	3.89	11.77	3.29	13.15
8	4.66	12.99	3.98	14.43
9	5.43	14.21	4.70	15.71
10	6.22	15.41	5.43	16.96

events in the absence of background, for confidence levels of 90% and 95%.

Table 39.4: Unified confidence intervals $[\mu_1, \mu_2]$ for a the mean of a Poisson variable given n observed events in the absence of background, for confidence levels of 90% and 95%.

	$1-\alpha$ =90%		$1-\alpha$ =95%	
n	μ_1	μ_2	μ_1	μ_2
0	0.00	2.44	0.00	3.09
1	0.11	4.36	0.05	5.14
2	0.53	5.91	0.36	6.72
3	1.10	7.42	0.82	8.25
4	1.47	8.60	1.37	9.76
5	1.84	9.99	1.84	11.26
6	2.21	11.47	2.21	12.75
7	3.56	12.53	2.58	13.81
8	3.96	13.99	2.94	15.29
9	4.36	15.30	4.36	16.77
10	5.50	16.50	4.75	17.82

Further discussion and all references may be found in the full *Review of Particle Physics.*

44. Clebsch-Gordan Coefficients, Spherical Harmonics, and *d* Functions

Note: A square-root sign is to be understood over *every* coefficient, *e.g.*, for −8/15 read $-\sqrt{8/15}$.

Notation:

m_1	m_2	J / M	J / M	…
m_1	m_2	Coefficients		
.	.			
.	.			

$$Y_1^0 = \sqrt{\frac{3}{4\pi}}\cos\theta$$

$$Y_1^1 = -\sqrt{\frac{3}{8\pi}}\sin\theta\, e^{i\phi}$$

$$Y_2^0 = \sqrt{\frac{5}{4\pi}}\left(\frac{3}{2}\cos^2\theta - \frac{1}{2}\right)$$

$$Y_2^1 = -\sqrt{\frac{15}{8\pi}}\sin\theta\cos\theta\, e^{i\phi}$$

$$Y_2^2 = \frac{1}{4}\sqrt{\frac{15}{2\pi}}\sin^2\theta\, e^{2i\phi}$$

$$Y_\ell^{-m} = (-1)^m Y_\ell^{m*}$$

$$\langle j_1 j_2 m_1 m_2 | j_1 j_2 J M\rangle = (-1)^{J-j_1-j_2}\langle j_2 j_1 m_2 m_1 | j_2 j_1 J M\rangle$$

1/2×1/2

m_1	m_2	J=1, M=+1
+1/2	+1/2	1

m_1	m_2	J=1, M=0	J=0, M=0
+1/2	−1/2	1/2	1/2
−1/2	+1/2	1/2	−1/2

m_1	m_2	J=1, M=−1
−1/2	−1/2	1

1×1/2

m_1	m_2	J=3/2, M=+3/2
+1	+1/2	1

m_1	m_2	J=3/2, M=+1/2	J=1/2, M=+1/2
+1	−1/2	1/3	2/3
0	+1/2	2/3	−1/3

m_1	m_2	J=3/2, M=−1/2	J=1/2, M=−1/2
0	−1/2	2/3	1/3
−1	+1/2	1/3	−2/3

m_1	m_2	J=3/2, M=−3/2
−1	−1/2	1

2×1

m_1	m_2	J=3, M=+3
+2	+1	1

m_1	m_2	J=3, M=+2	J=2, M=+2
+2	0	1/3	2/3
+1	+1	2/3	−1/3

m_1	m_2	J=3, M=+1	J=2, M=+1	J=1, M=+1
+2	−1	1/15	1/3	3/5
+1	0	8/15	1/6	−3/10
0	+1	2/5	−1/2	1/10

m_1	m_2	J=3, M=0	J=2, M=0	J=1, M=0
+1	−1	1/5	1/2	3/10
0	0	3/5	0	−2/5
−1	+1	1/5	−1/2	3/10

m_1	m_2	J=3, M=−1	J=2, M=−1	J=1, M=−1
0	−1	2/5	1/2	1/10
−1	0	8/15	−1/6	−3/10
−2	+1	1/15	−1/3	3/5

m_1	m_2	J=3, M=−2	J=2, M=−2
−1	−1	2/3	1/3
−2	0	1/3	−2/3

m_1	m_2	J=3, M=−3
−2	−1	1

1×1

m_1	m_2	J=2, M=+2
+1	+1	1

m_1	m_2	J=2, M=+1	J=1, M=+1
+1	0	1/2	1/2
0	+1	1/2	−1/2

m_1	m_2	J=2, M=0	J=1, M=0	J=0, M=0
+1	−1	1/6	1/2	1/3
0	0	2/3	0	−1/3
−1	+1	1/6	−1/2	1/3

m_1	m_2	J=2, M=−1	J=1, M=−1
0	−1	1/2	1/2
−1	0	1/2	−1/2

m_1	m_2	J=2, M=−2
−1	−1	1

3/2×1

m_1	m_2	J=5/2, M=+5/2
+3/2	+1	1

m_1	m_2	J=5/2, M=+3/2	J=3/2, M=+3/2
+3/2	0	2/5	3/5
+1/2	+1	3/5	−2/5

m_1	m_2	J=5/2, M=+1/2	J=3/2, M=+1/2	J=1/2, M=+1/2
+3/2	−1	1/10	2/5	1/2
+1/2	0	3/5	1/15	−1/3
−1/2	+1	3/10	−8/15	1/6

m_1	m_2	J=5/2, M=−1/2	J=3/2, M=−1/2	J=1/2, M=−1/2
+1/2	−1	3/10	8/15	1/6
−1/2	0	3/5	−1/15	−1/3
−3/2	+1	1/10	−2/5	1/2

m_1	m_2	J=5/2, M=−3/2	J=3/2, M=−3/2
−1/2	−1	3/5	2/5
−3/2	0	2/5	−3/5

m_1	m_2	J=5/2, M=−5/2
−3/2	−1	1

2×1/2

m_1	m_2	J=5/2, M=+5/2
+2	+1/2	1

m_1	m_2	J=5/2, M=+3/2	J=3/2, M=+3/2
+2	−1/2	1/5	4/5
+1	+1/2	4/5	−1/5

m_1	m_2	J=5/2, M=+1/2	J=3/2, M=+1/2
+1	−1/2	2/5	3/5
0	+1/2	3/5	−2/5

m_1	m_2	J=5/2, M=−1/2	J=3/2, M=−1/2
0	−1/2	3/5	2/5
−1	+1/2	2/5	−3/5

m_1	m_2	J=5/2, M=−3/2	J=3/2, M=−3/2
−1	−1/2	4/5	1/5
−2	+1/2	1/5	−4/5

m_1	m_2	J=5/2, M=−5/2
−2	−1/2	1

3/2×1/2

m_1	m_2	J=2, M=+2
+3/2	+1/2	1

m_1	m_2	J=2, M=+1	J=1, M=+1
+3/2	−1/2	1/4	3/4
+1/2	+1/2	3/4	−1/4

m_1	m_2	J=2, M=0	J=1, M=0
+1/2	−1/2	1/2	1/2
−1/2	+1/2	1/2	−1/2

m_1	m_2	J=2, M=−1	J=1, M=−1
−1/2	−1/2	3/4	1/4
−3/2	+1/2	1/4	−3/4

m_1	m_2	J=2, M=−2
−3/2	−1/2	1

$$d^{\ell}_{m,0} = \sqrt{\frac{4\pi}{2\ell+1}}\, Y^m_\ell\, e^{-im\phi}$$

$$d^{\,j}_{m',m} = (-1)^{m-m'} d^{\,j}_{m,m'} = d^{\,j}_{-m,-m'}$$

$$d^{1}_{0,0} = \cos\theta \qquad d^{1/2}_{1/2,1/2} = \cos\frac{\theta}{2} \qquad d^{1/2}_{1/2,-1/2} = -\sin\frac{\theta}{2}$$

$$d^{1}_{1,1} = \frac{1+\cos\theta}{2} \qquad d^{1}_{1,0} = -\frac{\sin\theta}{\sqrt{2}} \qquad d^{1}_{1,-1} = \frac{1-\cos\theta}{2}$$

2×3/2

	7/2
	+7/2
+2 +3/2	1

	7/2	5/2
	+5/2	+5/2
+2 +1/2	3/7	4/7
+1 +3/2	4/7	−3/7

	7/2	5/2	3/2
	+3/2	+3/2	+3/2
+2 −1/2	1/7	16/35	2/5
+1 +1/2	4/7	1/35	−2/5
0 +3/2	2/7	−18/35	1/5

	7/2	5/2	3/2	1/2
	+1/2	+1/2	+1/2	+1/2
+2 −3/2	1/35	6/35	2/5	2/5
+1 −1/2	12/35	5/14	0	−3/10
0 +1/2	18/35	−3/35	−1/5	1/5
−1 +3/2	4/35	−27/70	2/5	−1/10

	7/2	5/2	3/2	1/2
	−1/2	−1/2	−1/2	−1/2
+1 −3/2	4/35	27/70	2/5	1/10
0 −1/2	18/35	3/35	−1/5	−1/5
−1 +1/2	12/35	−5/14	0	3/10
−2 +3/2	1/35	−6/35	2/5	−2/5

	7/2	5/2	3/2
	−3/2	−3/2	−3/2
0 −3/2	2/7	18/35	1/5
−1 −1/2	4/7	−1/35	−2/5
−2 +1/2	1/7	−16/35	2/5

	7/2	5/2
	−5/2	−5/2
−1 −3/2	4/7	3/7
−2 −1/2	3/7	−4/7

	7/2
	−7/2
−2 −3/2	1

3/2×3/2

	3
	+3
+3/2 +3/2	1

	3	2
	+2	+2
+3/2 +1/2	1/2	1/2
+1/2 +3/2	1/2	−1/2

	3	2	1
	+1	+1	+1
+3/2 −1/2	1/5	1/2	3/10
+1/2 +1/2	3/5	0	−2/5
−1/2 +3/2	1/5	−1/2	3/10

	3	2	1	0
	0	0	0	0
+3/2 −3/2	1/20	1/4	9/20	1/4
+1/2 −1/2	9/20	1/4	−1/20	−1/4
−1/2 +1/2	9/20	−1/4	−1/20	1/4
−3/2 +3/2	1/20	−1/4	9/20	−1/4

	3	2	1
	−1	−1	−1
+1/2 −3/2	1/5	1/2	3/10
−1/2 −1/2	3/5	0	−2/5
−3/2 +1/2	1/5	−1/2	3/10

	3	2
	−2	−2
−1/2 −3/2	1/2	1/2
−3/2 −1/2	1/2	−1/2

	3
	−3
−3/2 −3/2	1

2×2

	4
	+4
+2 +2	1

	4	3
	+3	+3
+2 +1	1/2	1/2
+1 +2	1/2	−1/2

	4	3	2
	+2	+2	+2
+2 0	3/14	1/2	2/7
+1 +1	4/7	0	−3/7
0 +2	3/14	−1/2	2/7

	4	3	2	1
	+1	+1	+1	+1
+2 −1	1/14	3/10	3/7	1/5
+1 0	3/7	1/5	−1/14	−3/10
0 +1	3/7	−1/5	−1/14	3/10
−1 +2	1/14	−3/10	3/7	−1/5

	4	3	2	1	0
	0	0	0	0	0
+2 −2	1/70	1/10	2/7	2/5	1/5
+1 −1	8/35	2/5	1/14	−1/10	−1/5
0 0	18/35	0	−2/7	0	1/5
−1 +1	8/35	−2/5	1/14	1/10	−1/5
−2 +2	1/70	−1/10	2/7	−2/5	1/5

	4	3	2	1
	−1	−1	−1	−1
+1 −2	1/14	3/10	3/7	1/5
0 −1	3/7	1/5	−1/14	−3/10
−1 0	3/7	−1/5	−1/14	3/10
−2 +1	1/14	−3/10	3/7	−1/5

	4	3	2
	−2	−2	−2
0 −2	3/14	1/2	2/7
−1 −1	4/7	0	−3/7
−2 0	3/14	−1/2	2/7

	4	3
	−3	−3
−1 −2	1/2	1/2
−2 −1	1/2	−1/2

	4
	−4
−2 −2	1

$$d^{3/2}_{3/2,3/2} = \frac{1+\cos\theta}{2}\cos\frac{\theta}{2}$$

$$d^{3/2}_{3/2,1/2} = -\sqrt{3}\frac{1+\cos\theta}{2}\sin\frac{\theta}{2}$$

$$d^{3/2}_{3/2,-1/2} = \sqrt{3}\frac{1-\cos\theta}{2}\cos\frac{\theta}{2}$$

$$d^{3/2}_{3/2,-3/2} = -\frac{1-\cos\theta}{2}\sin\frac{\theta}{2}$$

$$d^{3/2}_{1/2,1/2} = \frac{3\cos\theta-1}{2}\cos\frac{\theta}{2}$$

$$d^{3/2}_{1/2,-1/2} = -\frac{3\cos\theta+1}{2}\sin\frac{\theta}{2}$$

$$d^{2}_{2,2} = \left(\frac{1+\cos\theta}{2}\right)^2$$

$$d^{2}_{2,1} = -\frac{1+\cos\theta}{2}\sin\theta$$

$$d^{2}_{2,0} = \frac{\sqrt{6}}{4}\sin^2\theta$$

$$d^{2}_{2,-1} = -\frac{1-\cos\theta}{2}\sin\theta$$

$$d^{2}_{2,-2} = \left(\frac{1-\cos\theta}{2}\right)^2$$

$$d^{2}_{1,1} = \frac{1+\cos\theta}{2}(2\cos\theta-1)$$

$$d^{2}_{1,0} = -\sqrt{\frac{3}{2}}\sin\theta\cos\theta$$

$$d^{2}_{1,-1} = \frac{1-\cos\theta}{2}(2\cos\theta+1)$$

$$d^{2}_{0,0} = \left(\frac{3}{2}\cos^2\theta-\frac{1}{2}\right)$$

47. Kinematics

Revised August 2017 by D.R. Tovey (Sheffield) and January 2000 by J.D. Jackson (LBNL).

Throughout this section units are used in which $\hbar = c = 1$. The following conversions are useful: $\hbar c = 197.3$ MeV fm, $(\hbar c)^2 = 0.3894$ (GeV)^2 mb.

47.1. Lorentz transformations

The energy E and 3-momentum $\boldsymbol{p}$ of a particle of mass m form a 4-vector $p = (E, \boldsymbol{p})$ whose square $p^2 \equiv E^2 - |\boldsymbol{p}|^2 = m^2$. The velocity of the particle is $\boldsymbol{\beta} = \boldsymbol{p}/E$. The energy and momentum $(E^*, \boldsymbol{p}^*)$ viewed from a frame moving with velocity $\boldsymbol{\beta}_f$ are given by

$$\begin{pmatrix} E^* \\ p_\parallel^* \end{pmatrix} = \begin{pmatrix} \gamma_f & -\gamma_f\beta_f \\ -\gamma_f\beta_f & \gamma_f \end{pmatrix} \begin{pmatrix} E \\ p_\parallel \end{pmatrix} , \qquad p_T^* = p_T , \tag{47.1}$$

where $\gamma_f = (1-\beta_f^2)^{-1/2}$ and p_T $(p_\parallel)$ are the components of $\boldsymbol{p}$ perpendicular (parallel) to $\boldsymbol{\beta}_f$. Other 4-vectors, such as the space-time coordinates of events, of course transform in the same way. The scalar product of two 4-momenta $p_1 \cdot p_2 = E_1 E_2 - \boldsymbol{p}_1 \cdot \boldsymbol{p}_2$ is invariant (frame independent).

47.2. Center-of-mass energy and momentum

In the collision of two particles of masses m_1 and m_2 the total center-of-mass energy can be expressed in the Lorentz-invariant form

$$\begin{aligned} E_{\rm cm} &= \Big[(E_1 + E_2)^2 - (\boldsymbol{p}_1 + \boldsymbol{p}_2)^2\Big]^{1/2} , \\ &= \Big[m_1^2 + m_2^2 + 2E_1E_2(1 - \beta_1\beta_2\cos\theta)\Big]^{1/2} , \end{aligned} \tag{47.2}$$

where θ is the angle between the particles. In the frame where one particle (of mass m_2) is at rest (lab frame),

$$E_{\rm cm} = (m_1^2 + m_2^2 + 2E_{1\,\rm lab}\, m_2)^{1/2} . \tag{47.3}$$

The velocity of the center-of-mass in the lab frame is

$$\boldsymbol{\beta}_{\rm cm} = \boldsymbol{p}_{\rm lab}/(E_{1\,\rm lab} + m_2) , \tag{47.4}$$

where $\boldsymbol{p}_{\rm lab} \equiv \boldsymbol{p}_{1\,\rm lab}$ and

$$\gamma_{\rm cm} = (E_{1\,\rm lab} + m_2)/E_{\rm cm} . \tag{47.5}$$

The c.m. momenta of particles 1 and 2 are of magnitude

$$p_{\rm cm} = p_{\rm lab} \frac{m_2}{E_{\rm cm}} . \tag{47.6}$$

For example, if a 0.80 GeV/c kaon beam is incident on a proton target, the center of mass energy is 1.699 GeV and the center of mass momentum of either particle is 0.442 GeV/c. It is also useful to note that

$$E_{\rm cm}\, dE_{\rm cm} = m_2\, dE_{1\,\rm lab} = m_2\, \beta_{1\,\rm lab}\, dp_{\rm lab} . \tag{47.7}$$

47.3. Lorentz-invariant amplitudes

The matrix elements for a scattering or decay process are written in terms of an invariant amplitude $-i\mathscr{M}$. As an example, the S-matrix for $2 \to 2$ scattering is related to $\mathscr{M}$ by

$$\begin{aligned} \langle p_1' p_2' \,|S|\, p_1 p_2\rangle &= I - i(2\pi)^4\, \delta^4(p_1 + p_2 - p_1' - p_2') \\ &\times \frac{\mathscr{M}(p_1, p_2;\, p_1', p_2')}{(2E_1)^{1/2}\,(2E_2)^{1/2}\,(2E_1')^{1/2}\,(2E_2')^{1/2}} . \end{aligned} \tag{47.8}$$

The state normalization is such that

$$\langle p'|p\rangle = (2\pi)^3\delta^3(\boldsymbol{p}-\boldsymbol{p}') \ . \tag{47.9}$$

47.4. Particle decays

The partial decay rate of a particle of mass M into n bodies in its rest frame is given in terms of the Lorentz-invariant matrix element $\mathscr{M}$ by

$$d\Gamma = \frac{(2\pi)^4}{2M}\,|\mathscr{M}|^2\,d\Phi_n\,(P;\,p_1,\,\ldots,\,p_n), \tag{47.11}$$

where $d\Phi_n$ is an element of n-body phase space given by

$$d\Phi_n(P;\,p_1,\,\ldots,\,p_n) = \delta^4\,(P - \sum_{i=1}^{n} p_i)\,\prod_{i=1}^{n}\frac{d^3p_i}{(2\pi)^3 2E_i} \ . \tag{47.12}$$

This phase space can be generated recursively, viz.

$$\begin{aligned} d\Phi_n(P;\,p_1,\,\ldots,\,p_n) &= d\Phi_j(q;\,p_1,\,\ldots,\,p_j) \\ \times\ d\Phi_{n-j+1}\,(P;\,q,\,p_{j+1},\,\ldots,\,p_n)&(2\pi)^3 dq^2 \ , \end{aligned} \tag{47.13}$$

where $q^2 = (\sum_{i=1}^{j} E_i)^2 - \left|\sum_{i=1}^{j}\boldsymbol{p}_i\right|^2$. This form is particularly useful in the case where a particle decays into another particle that subsequently decays.

47.4.1. ***Survival probability*** : If a particle of mass M has mean proper lifetime τ $(=1/\Gamma)$ and has momentum $(E,\boldsymbol{p})$, then the probability that it lives for a time t_0 or greater before decaying is given by

$$P(t_0) = e^{-t_0\,\Gamma/\gamma} = e^{-Mt_0\,\Gamma/E} \ , \tag{47.14}$$

and the probability that it travels a distance x_0 or greater is

$$P(x_0) = e^{-Mx_0\,\Gamma/|\boldsymbol{p}|} \ . \tag{47.15}$$

47.4.2. ***Two-body decays*** :

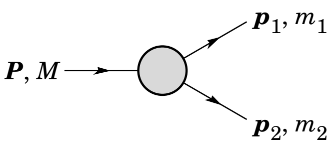


Figure 47.1: Definitions of variables for two-body decays.

In the rest frame of a particle of mass M, decaying into 2 particles labeled 1 and 2,

$$E_1 = \frac{M^2 - m_2^2 + m_1^2}{2M} \ , \tag{47.16}$$

$$\begin{aligned} |\boldsymbol{p}_1| &= |\boldsymbol{p}_2| \\ &= \frac{\left[\left(M^2-(m_1+m_2)^2\right)\left(M^2-(m_1-m_2)^2\right)\right]^{1/2}}{2M} \ , \end{aligned} \tag{47.17}$$

and

$$d\Gamma = \frac{1}{32\pi^2}\,|\mathscr{M}|^2\,\frac{|\boldsymbol{p}_1|}{M^2}\,d\Omega \ , \tag{47.18}$$

where $d\Omega = d\phi_1 d(\cos\theta_1)$ is the solid angle of particle 1. The invariant mass M can be determined from the energies and momenta using Eq. (47.2) with $M = E_{\rm cm}$.

47.4.3. *Three-body decays* :

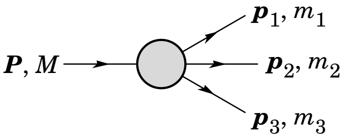


Figure 47.2: Definitions of variables for three-body decays.

Defining $p_{ij} = p_i + p_j$ and $m_{ij}^2 = p_{ij}^2$, then $m_{12}^2 + m_{23}^2 + m_{13}^2 = M^2 + m_1^2 + m_2^2 + m_3^2$ and $m_{12}^2 = (P - p_3)^2 = M^2 + m_3^2 - 2ME_3$, where E_3 is the energy of particle 3 in the rest frame of M. In that frame, the momenta of the three decay particles lie in a plane. The relative orientation of these three momenta is fixed if their energies are known. The momenta can therefore be specified in space by giving three Euler angles (α, β, γ) that specify the orientation of the final system relative to the initial particle. The direction of any one of the particles relative to the frame in which the initial particle is described can be specified in space by two angles (α, β) while a third angle, γ, can be set as the azimuthal angle of a second particle around the first [1]. Then

$$d\Gamma = \frac{1}{(2\pi)^5} \frac{1}{16M} \, |\mathscr{M}|^2 \, dE_1 \, dE_3 \, d\alpha \, d(\cos\beta) \, d\gamma \; . \tag{47.19}$$

Alternatively

$$d\Gamma = \frac{1}{(2\pi)^5} \frac{1}{16M^2} \, |\mathscr{M}|^2 \, |\boldsymbol{p}_1^*| \, |\boldsymbol{p}_3| \, dm_{12} \, d\Omega_1^* \, d\Omega_3 \; , \tag{47.20}$$

where $(|\boldsymbol{p}_1^*|, \, \Omega_1^*)$ is the momentum of particle 1 in the rest frame of 1 and 2, and Ω_3 is the angle of particle 3 in the rest frame of the decaying particle. $|\boldsymbol{p}_1^*|$ and $|\boldsymbol{p}_3|$ are given by

$$|\boldsymbol{p}_1^*| = \frac{\left[\left(m_{12}^2 - (m_1 + m_2)^2\right)\left(m_{12}^2 - (m_1 - m_2)^2\right)\right]^{1/2}}{2m_{12}} \; , \tag{47.21a}$$

and

$$|\boldsymbol{p}_3| = \frac{\left[\left(M^2 - (m_{12} + m_3)^2\right)\left(M^2 - (m_{12} - m_3)^2\right)\right]^{1/2}}{2M} \; . \tag{47.21b}$$

[Compare with Eq. (47.17).]

If the decaying particle is a scalar or we average over its spin states, then integration over the angles in Eq. (47.19) gives

$$\begin{aligned} d\Gamma &= \frac{1}{(2\pi)^3} \frac{1}{8M} \, \overline{|\mathscr{M}|^2} \, dE_1 \, dE_3 \\ &= \frac{1}{(2\pi)^3} \frac{1}{32M^3} \, \overline{|\mathscr{M}|^2} \, dm_{12}^2 \, dm_{23}^2 \; . \end{aligned} \tag{47.22}$$

This is the standard form for the Dalitz plot.

47.4.3.1. *Dalitz plot:* For a given value of m_{12}^2, the range of m_{23}^2 is determined by its values when $\boldsymbol{p}_2$ is parallel or antiparallel to $\boldsymbol{p}_3$:

$$(m_{23}^2)_{\max} =$$

$$(E_2^* + E_3^*)^2 - \left(\sqrt{E_2^{*2} - m_2^2} - \sqrt{E_3^{*2} - m_3^2}\right)^2 , \tag{47.23a}$$

$$(m_{23}^2)_{\min} =$$

$$(E_2^* + E_3^*)^2 - \left(\sqrt{E_2^{*2} - m_2^2} + \sqrt{E_3^{*2} - m_3^2}\right)^2 . \tag{47.23b}$$

Here $E_2^* = (m_{12}^2 - m_1^2 + m_2^2)/2m_{12}$ and $E_3^* = (M^2 - m_{12}^2 - m_3^2)/2m_{12}$ are the energies of particles 2 and 3 in the m_{12} rest frame. The scatter plot in m_{12}^2 and m_{23}^2 is called a Dalitz plot. If $\overline{|\mathscr{M}|^2}$ is constant, the allowed region of the plot will be uniformly populated with events [see Eq. (47.22)]. A nonuniformity in the plot gives immediate information on $|\mathscr{M}|^2$. For example, in the case of $D \to K\pi\pi$, bands appear when $m_{(K\pi)} = m_{K^*(892)}$, reflecting the appearance of the decay chain $D \to K^*(892)\pi \to K\pi\pi$.

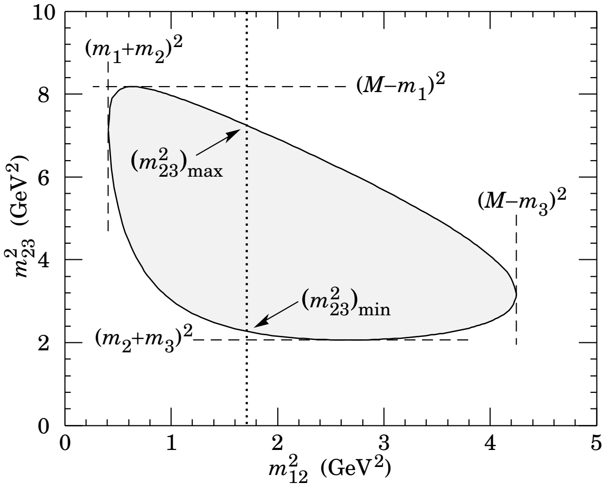


Figure 47.3: Dalitz plot for a three-body final state. In this example, the state is $\pi^+\overline{K}^0p$ at 3 GeV. Four-momentum conservation restricts events to the shaded region.

47.4.4. *Kinematic limits* :

47.4.4.1. *Three-body decays:* In a three-body decay (Fig. 47.2) the maximum of $|\boldsymbol{p}_3|$, [given by Eq. (47.21)], is achieved when $m_{12} = m_1 + m_2$, *i.e.*, particles 1 and 2 have the same vector velocity in the rest frame of the decaying particle. If, in addition, $m_3 > m_1, m_2$, then $|\boldsymbol{p}_3|_{\max} > |\boldsymbol{p}_1|_{\max}$, $|\boldsymbol{p}_2|_{\max}$. The distribution of m_{12} values possesses an end-point or maximum value at $m_{12} = M - m_3$. This can be used to constrain the mass difference of a parent particle and one invisible decay product.

47.4.5. *Multibody decays* : The above results may be generalized to final states containing any number of particles by combining some of the particles into "effective particles" and treating the final states as 2 or 3 "effective particle" states. Thus, if $p_{ijk\ldots} = p_i + p_j + p_k + \ldots$, then

$$m_{ijk\ldots} = \sqrt{p^2{}_{ijk\ldots}} \ , \tag{47.26}$$

and $m_{ijk\ldots}$ may be used in place of *e.g.*, m_{12} in the relations in Sec. 47.4.3 or Sec. 47.4.4 above.

47.5. Cross sections

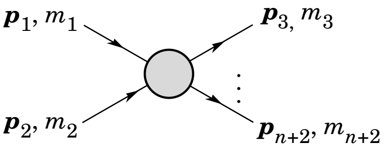


Figure 47.5: Definitions of variables for production of an n-body final state.

The differential cross section is given by

$$d\sigma = \frac{(2\pi)^4 |\mathscr{M}|^2}{4\sqrt{(p_1 \cdot p_2)^2 - m_1^2 m_2^2}} \times \ d\Phi_n(p_1 + p_2;\ p_3, \ldots, p_{n+2}) \ . \tag{47.27}$$

[See Eq. (47.12).] In the rest frame of m_2(lab),

$$\sqrt{(p_1 \cdot p_2)^2 - m_1^2 m_2^2} = m_2 p_{1\,\mathrm{lab}} \ ; \tag{47.28a}$$

while in the center-of-mass frame

$$\sqrt{(p_1 \cdot p_2)^2 - m_1^2 m_2^2} = p_{1\mathrm{cm}} \sqrt{s} \ . \tag{47.28b}$$

47.5.1. *Two-body reactions* :

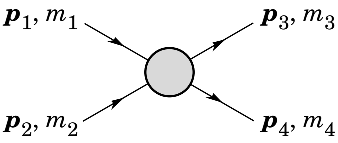


Figure 47.6: Definitions of variables for a two-body final state.

Two particles of momenta p_1 and p_2 and masses m_1 and m_2 scatter to particles of momenta p_3 and p_4 and masses m_3 and m_4; the Lorentz-invariant Mandelstam variables are defined by

$$\begin{aligned} s &= (p_1 + p_2)^2 = (p_3 + p_4)^2 \\ &= m_1^2 + 2E_1E_2 - 2\boldsymbol{p}_1 \cdot \boldsymbol{p}_2 + m_2^2 \ , \end{aligned} \tag{47.29}$$

$$\begin{aligned} t &= (p_1 - p_3)^2 = (p_2 - p_4)^2 \\ &= m_1^2 - 2E_1E_3 + 2\boldsymbol{p}_1 \cdot \boldsymbol{p}_3 + m_3^2 \ , \end{aligned} \tag{47.30}$$

$$u = (p_1 - p_4)^2 = (p_2 - p_3)^2$$
$$= m_1^2 - 2E_1 E_4 + 2\boldsymbol{p}_1 \cdot \boldsymbol{p}_4 + m_4^2 \; , \tag{47.31}$$

and they satisfy

$$s + t + u = m_1^2 + m_2^2 + m_3^2 + m_4^2 \; . \tag{47.32}$$

The two-body cross section may be written as

$$\frac{d\sigma}{dt} = \frac{1}{64\pi s} \, \frac{1}{|\boldsymbol{p}_{1\text{cm}}|^2} \, |\mathscr{M}|^2 \; . \tag{47.33}$$

In the center-of-mass frame

$$t = (E_{1\text{cm}} - E_{3\text{cm}})^2 - (p_{1\text{cm}} - p_{3\text{cm}})^2 \qquad - 4p_{1\text{cm}}\, p_{3\text{cm}} \, \sin^2(\theta_{\text{cm}}/2)$$

$$= t_0 - 4p_{1\text{cm}}\, p_{3\text{cm}} \, \sin^2(\theta_{\text{cm}}/2) \; , \tag{47.34}$$

where θ_{cm} is the angle between particle 1 and 3. The limiting values t_0 $(\theta_{\text{cm}} = 0)$ and t_1 $(\theta_{\text{cm}} = \pi)$ for $2 \to 2$ scattering are

$$t_0(t_1) = \left[\frac{m_1^2 - m_3^2 - m_2^2 + m_4^2}{2\sqrt{s}}\right]^2 - (p_{1\,\text{cm}} \mp p_{3\,\text{cm}})^2 \; . \tag{47.35}$$

In the literature the notation t_{min} (t_{max}) for t_0 (t_1) is sometimes used, which should be discouraged since $t_0 > t_1$. The center-of-mass energies and momenta of the incoming particles are

$$E_{1\text{cm}} = \frac{s + m_1^2 - m_2^2}{2\sqrt{s}} \; , \qquad E_{2\text{cm}} = \frac{s + m_2^2 - m_1^2}{2\sqrt{s}} \; , \tag{47.36}$$

For $E_{3\text{cm}}$ and $E_{4\text{cm}}$, change m_1 to m_3 and m_2 to m_4. Then

$$p_{i\,\text{cm}} = \sqrt{E_{i\,\text{cm}}^2 - m_i^2} \text{ and } p_{1\text{cm}} = \frac{p_{1\,\text{lab}}\, m_2}{\sqrt{s}} \; . \tag{47.37}$$

Here the subscript lab refers to the frame where particle 2 is at rest. [For other relations see Eqs. (47.2)–(47.4).]

47.5.2. ***Inclusive reactions*** : Choose some direction (usually the beam direction) for the z-axis; then the energy and momentum of a particle can be written as

$$E = m_T \cosh y \; , \; p_x \; , \; p_y \; , \; p_z = m_T \sinh y \; , \tag{47.38}$$

where m_T, conventionally called the 'transverse mass', is given by

$$m_T^2 = m^2 + p_x^2 + p_y^2 \; . \tag{47.39}$$

and the rapidity y is defined by

$$y = \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z}\right)$$

$$= \ln \left(\frac{E + p_z}{m_T}\right) = \tanh^{-1}\left(\frac{p_z}{E}\right) \; . \tag{47.40}$$

Note that the definition of the transverse mass in Eq. (47.39) differs from that used by experimentalists at hadron colliders (see Sec. 47.6.1 below). Under a boost in the z-direction to a frame with velocity β, $y \to y - \tanh^{-1}\beta$. Hence the shape of the rapidity distribution dN/dy is invariant, as are differences in rapidity. The invariant cross section may also be rewritten

$$E\frac{d^3\sigma}{d^3p} = \frac{d^3\sigma}{d\phi\, dy\, p_T dp_T} \Longrightarrow \frac{d^2\sigma}{\pi\, dy\, d(p_T^2)} \ . \tag{47.41}$$

The second form is obtained using the identity $dy/dp_z = 1/E$, and the third form represents the average over ϕ.

Feynman's x variable is given by

$$x = \frac{p_z}{p_{z\,\max}} \approx \frac{E + p_z}{(E + p_z)_{\max}} \quad (p_T \ll |p_z|) \ . \tag{47.42}$$

In the c.m. frame,

$$x \approx \frac{2p_{z\,\mathrm{cm}}}{\sqrt{s}} = \frac{2m_T \sinh y_{\mathrm{cm}}}{\sqrt{s}} \tag{47.43}$$

and

$$= (y_{\mathrm{cm}})_{\max} = \ln(\sqrt{s}/m) \ . \tag{47.44}$$

The invariant mass M of the two-particle system described in Sec. 47.4.2 can be written in terms of these variables as

$$M^2 = m_1^2 + m_2^2 + 2[E_T(1)E_T(2)\cosh\Delta y - \boldsymbol{p}_T(1)\cdot\boldsymbol{p}_T(2)] \ , \tag{47.45}$$

where

$$E_T(i) = \sqrt{|\boldsymbol{p}_T(i)|^2 + m_i^2} \ , \tag{47.46}$$

and $\boldsymbol{p}_T(i)$ denotes the transverse momentum vector of particle i.

For $p \gg m$, the rapidity [Eq. (47.40)] may be expanded to obtain

$$\begin{aligned} y &= \frac{1}{2}\ln\frac{\cos^2(\theta/2) + m^2/4p^2 + \ldots}{\sin^2(\theta/2) + m^2/4p^2 + \ldots} \\ &\approx -\ln\tan(\theta/2) \equiv \eta \end{aligned} \tag{47.47}$$

where $\cos\theta = p_z/p$. The pseudorapidity η defined by the second line is approximately equal to the rapidity y for $p \gg m$ and $\theta \gg 1/\gamma$, and in any case can be measured when the mass and momentum of the particle are unknown. From the definition one can obtain the identities

$$\sinh\eta = \cot\theta \ , \quad \cosh\eta = 1/\sin\theta \ , \quad \tanh\eta = \cos\theta \ . \tag{47.48}$$

47.6. Transverse variables

At hadron colliders, a significant and unknown proportion of the energy of the incoming hadrons in each event escapes down the beam-pipe. Consequently if invisible particles are created in the final state, their net momentum can only be constrained in the plane transverse to the beam direction. Defining the z-axis as the beam direction, this net momentum is equal to the missing transverse energy vector

$$\boldsymbol{E}_T^{\mathrm{miss}} = -\sum_i \boldsymbol{p}_T(i) \ , \tag{47.49}$$

where the sum runs over the transverse momenta of all visible final state particles.

47.6.1. *Single production with semi-invisible final state* :

Consider a single heavy particle of mass M produced in association with visible particles which decays as in Fig. 47.1 to two particles, of which one (labeled particle 1) is invisible. The mass of the parent particle can be constrained with the quantity M_T defined by

$$\begin{aligned} M_T^2 &\equiv [E_T(1) + E_T(2)]^2 - [\boldsymbol{p}_T(1) + \boldsymbol{p}_T(2)]^2 \\ &= m_1^2 + m_2^2 + 2[E_T(1)E_T(2) - \boldsymbol{p}_T(1) \cdot \boldsymbol{p}_T(2)] , \end{aligned} \tag{47.50}$$

where

$$\boldsymbol{p}_T(1) = \boldsymbol{E}_T^{\text{miss}} . \tag{47.51}$$

This quantity is called the 'transverse mass' by hadron collider experimentalists but it should be noted that it is quite different from that used in the description of inclusive reactions [Eq. (47.39)]. The distribution of event M_T values possesses an end-point at $M_T^{\max} = M$. If $m_1 = m_2 = 0$ then

$$M_T^2 = 2|\boldsymbol{p}_T(1)||\boldsymbol{p}_T(2)|(1 - \cos\phi_{12}) , \tag{47.52}$$

where ϕ_{ij} is defined as the angle between particles i and j in the transverse plane.

47.6.2. *Pair production with semi-invisible final states* :

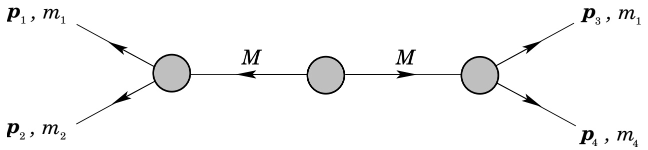


Figure 47.7: Definitions of variables for pair production of semi-invisible final states. Particles 1 and 3 are invisible while particles 2 and 4 are visible.

Consider two identical heavy particles of mass M produced such that their combined center-of-mass is at rest in the transverse plane (Fig. 47.7). Each particle decays to a final state consisting of an invisible particle of fixed mass m_1 together with an additional visible particle. M and m_1 can be constrained with the variables M_{T2} and M_{CT} which are defined in Refs. [4] and [5].

Further discussion and all references may be found in the full *Review of Particle Physics*. The numbering of references and equations used here corresponds to that version.

49. Cross-section formulae for specific processes

Revised October 2009 by H. Baer (University of Oklahoma) and R.N. Cahn (LBNL).

PART I: Standard Model Processes

Setting aside leptoproduction (for which, see Sec. 16 of this *Review*), the cross sections of primary interest are those with light incident particles, e^+e^-, $\gamma\gamma$, $q\overline{q}$, gq , gg, *etc.*, where g and q represent gluons and light quarks. The produced particles include both light particles and heavy ones - t, W, Z, and the Higgs boson H. We provide the production cross sections calculated within the Standard Model for several such processes.

49.1. Resonance Formation

Resonant cross sections are generally described by the Breit-Wigner formula (Sec. 18 of this *Review*).

$$\sigma(E) = \frac{2J+1}{(2S_1+1)(2S_2+1)}\frac{4\pi}{k^2}\left[\frac{\Gamma^2/4}{(E-E_0)^2+\Gamma^2/4}\right]B_{in}B_{out}, \qquad (49.1)$$

where E is the c.m. energy, J is the spin of the resonance, and the number of polarization states of the two incident particles are $2S_1+1$ and $2S_2+1$. The c.m. momentum in the initial state is k, E_0 is the c.m. energy at the resonance, and Γ is the full width at half maximum height of the resonance. The branching fraction for the resonance into the initial-state channel is B_{in} and into the final-state channel is B_{out}. For a narrow resonance, the factor in square brackets may be replaced by $\pi\Gamma\delta(E-E_0)/2$.

49.2. Production of light particles

The production of point-like, spin-1/2 fermions in e^+e^- annihilation through a virtual photon, $e^+e^-\to\gamma^*\to f\overline{f}$, at c.m. energy squared s is

$$\frac{d\sigma}{d\Omega} = N_c\frac{\alpha^2}{4s}\beta[1+\cos^2\theta+(1-\beta^2)\sin^2\theta]Q_f^2\ , \qquad (49.2)$$

where β is v/c for the produced fermions in the c.m., θ is the c.m. scattering angle, and Q_f is the charge of the fermion. The factor N_c is 1 for charged leptons and 3 for quarks. In the ultrarelativistic limit, $\beta\to 1$,

$$\sigma = N_cQ_f^2\frac{4\pi\alpha^2}{3s} = N_cQ_f^2\frac{86.8\ \text{nb}}{s\,(\text{GeV}^2)}\ . \qquad (49.3)$$

The cross section for the annihilation of a $q\overline{q}$ pair into a distinct pair $q'\overline{q}'$ through a gluon is completely analogous up to color factors, with the replacement $\alpha\to\alpha_s$. Treating all quarks as massless, averaging over the colors of the initial quarks and defining $t=-s\sin^2(\theta/2)$, $u=-s\cos^2(\theta/2)$, one finds

$$\frac{d\sigma}{d\Omega}(q\overline{q}\to q'\overline{q}') = \frac{\alpha_s^2}{9s}\frac{t^2+u^2}{s^2}\ . \qquad (49.4)$$

Crossing symmetry gives

$$\frac{d\sigma}{d\Omega}(qq'\to qq') = \frac{\alpha_s^2}{9s}\frac{s^2+u^2}{t^2}\ . \qquad (49.5)$$

If the quarks q and q' are identical, we have

$$\frac{d\sigma}{d\Omega}(q\overline{q}\to q\overline{q}) = \frac{\alpha_s^2}{9s}\left[\frac{t^2+u^2}{s^2}+\frac{s^2+u^2}{t^2}-\frac{2u^2}{3st}\right]\ , \qquad (49.6)$$

and by crossing

$$\frac{d\sigma}{d\Omega}(qq \to qq) = \frac{\alpha_s^2}{9s}\left[\frac{t^2+s^2}{u^2} + \frac{s^2+u^2}{t^2} - \frac{2s^2}{3ut}\right] . \tag{49.7}$$

Annihilation of e^+e^- into $\gamma\gamma$ has the cross section

$$\frac{d\sigma}{d\Omega}(e^+e^- \to \gamma\gamma) = \frac{\alpha^2}{2s}\frac{u^2+t^2}{tu} . \tag{49.8}$$

The related QCD process also has a triple-gluon coupling. The cross section is

$$\frac{d\sigma}{d\Omega}(q\overline{q} \to gg) = \frac{8\alpha_s^2}{27s}(t^2+u^2)(\frac{1}{tu} - \frac{9}{4s^2}) . \tag{49.9}$$

The crossed reactions are

$$\frac{d\sigma}{d\Omega}(qg \to qg) = \frac{\alpha_s^2}{9s}(s^2+u^2)(-\frac{1}{su} + \frac{9}{4t^2}) , \tag{49.10}$$

$$\frac{d\sigma}{d\Omega}(gg \to q\overline{q}) = \frac{\alpha_s^2}{24s}(t^2+u^2)(\frac{1}{tu} - \frac{9}{4s^2}) , \tag{49.11}$$

$$\frac{d\sigma}{d\Omega}(gg \to gg) = \frac{9\alpha_s^2}{8s}(3 - \frac{ut}{s^2} - \frac{su}{t^2} - \frac{st}{u^2}) . \tag{49.12}$$

Lepton-quark scattering is analogous (neglecting Z exchange)

$$\frac{d\sigma}{d\Omega}(eq \to eq) = \frac{\alpha^2}{2s}e_q^2\frac{s^2+u^2}{t^2} , \tag{49.13}$$

e_q is the quark charge. For ν-scattering with the four-Fermi interaction

$$\frac{d\sigma}{d\Omega}(\nu d \to \ell^- u) = \frac{G_F^2 s}{4\pi^2} , \tag{49.14}$$

where the Cabibbo angle suppression is ignored. Similarly

$$\frac{d\sigma}{d\Omega}(\nu\overline{u} \to \ell^-\overline{d}) = \frac{G_F^2 s}{4\pi^2}\frac{(1+\cos\theta)^2}{4} . \tag{49.15}$$

For deep inelastic scattering (presented in more detail in Section 19) we consider quarks of type i carrying a fraction $x = Q^2/(2M\nu)$ of the nucleon's energy, where $\nu = E - E'$ is the energy lost by the lepton in the nucleon rest frame. With $y = \nu/E$ we have the correspondences

$$1+\cos\theta \to 2(1-y) , \qquad d\Omega_{cm} \to 4\pi f_i(x) dx\, dy , \tag{49.16}$$

where the latter incorporates the quark distribution, $f_i(x)$. We find

$$\frac{d\sigma}{dx\, dy}(eN \to eX) = \frac{4\pi\alpha^2 xs}{Q^4}\frac{1}{2}\left[1+(1-y)^2\right]$$
$$\times \left[\frac{4}{9}(u(x)+\overline{u}(x)+\ldots)+\frac{1}{9}(d(x)+\overline{d}(x)+\ldots)\right] \tag{49.17}$$

where now $s = 2ME$ is the cm energy squared for the electron-nucleon collision and we have suppressed contributions from higher mass quarks.

Similarly,

$$\frac{d\sigma}{dx\, dy}(\nu N \to \ell^- X) = \frac{G_F^2 xs}{\pi}[(d(x)+\ldots)+(1-y)^2(\overline{u}(x)+\ldots)] , \tag{49.18}$$

$$\frac{d\sigma}{dx\, dy}(\overline{\nu} N \to \ell^+ X) = \frac{G_F^2 xs}{\pi}[(\overline{d}(x)+\ldots)+(1-y)^2(u(x)+\ldots)] . \tag{49.19}$$

Quasi-elastic neutrino scattering ($\nu_\mu n \to \mu^- p$, $\overline{\nu}_\mu p \to \mu^+ n$) is directly related to the crossed reaction, neutron decay.

49.3. Hadroproduction of heavy quarks

For hadroproduction of heavy quarks $Q = c,\ b,\ t$, it is important to include mass effects in the formulae. For $q\bar{q} \to Q\bar{Q}$, one has

$$\frac{d\sigma}{d\Omega}(q\bar{q} \to Q\bar{Q}) = \frac{\alpha_s^2}{9s^3}\sqrt{1-\frac{4m_Q^2}{s}}\left[(m_Q^2-t)^2+(m_Q^2-u)^2+2m_Q^2 s\right], \tag{49.20}$$

while for $gg \to Q\bar{Q}$ one has

$$\begin{aligned}\frac{d\sigma}{d\Omega}(gg \to Q\bar{Q}) &= \frac{\alpha_s^2}{32s}\sqrt{1-\frac{4m_Q^2}{s}}\left[\frac{6}{s^2}(m_Q^2-t)(m_Q^2-u)\right.\\
&-\frac{m_Q^2(s-4m_Q^2)}{3(m_Q^2-t)(m_Q^2-u)}+\frac{4}{3}\frac{(m_Q^2-t)(m_Q^2-u)-2m_Q^2(m_Q^2+t)}{(m_Q^2-t)^2}\\
&+\frac{4}{3}\frac{(m_Q^2-t)(m_Q^2-u)-2m_Q^2(m_Q^2+u)}{(m_Q^2-u)^2}\\
&\left.-3\frac{(m_Q^2-t)(m_Q^2-u)+m_Q^2(u-t)}{s(m_Q^2-t)}-3\frac{(m_Q^2-t)(m_Q^2-u)+m_Q^2(t-u)}{s(m_Q^2-u)}\right].\end{aligned} \tag{49.21}$$

49.4. Production of Weak Gauge Bosons

49.4.1. *W and Z resonant production* :

Resonant production of a single W or Z is governed by the partial widths

$$\Gamma(W \to \ell_i\overline{\nu}_i) = \frac{\sqrt{2}G_F m_W^3}{12\pi} \tag{49.22}$$

$$\Gamma(W \to q_i\overline{q}_j) = 3\frac{\sqrt{2}G_F|V_{ij}|^2 m_W^3}{12\pi} \tag{49.23}$$

$$\begin{aligned}\Gamma(Z \to f\overline{f}) &= N_c\frac{\sqrt{2}G_F m_Z^3}{6\pi}\\
&\times\left[(T_3-Q_f\sin^2\theta_W)^2+(Q_f\sin^2\theta_W)^2\right].\end{aligned} \tag{49.24}$$

The weak mixing angle is θ_W. The CKM matrix elements are V_{ij}. N_c is 3 for $q\overline{q}$ and 1 for leptonic final states. These widths along with associated branching fractions may be applied to the resonance production formula of Sec. 49.1 to gain the total W or Z production cross section.

49.4.2. *Production of pairs of weak gauge bosons* :

The cross section for $f\overline{f} \to W^+W^-$ is given in term of the couplings of the left-handed and right-handed fermion f, $\ell = 2(T_3 - Qx_W)$, $r = -2Qx_W$, where T_3 is the third component of weak isospin for the left-handed f, Q is its electric charge (in units of the proton charge), and $x_W = \sin^2\theta_W$:

$$\begin{aligned}\frac{d\sigma}{dt} = \frac{2\pi\alpha^2}{N_c s^2}&\left\{\left[\left(Q+\frac{\ell+r}{4x_W}\frac{s}{s-m_Z^2}\right)^2+\left(\frac{\ell-r}{4x_W}\frac{s}{s-m_Z^2}\right)^2\right]A(s,t,u)\right.\\
&+\frac{1}{2x_W}\left(Q+\frac{\ell}{2x_W}\frac{s}{s-m_Z^2}\right)(\Theta(-Q)I(s,t,u)-\Theta(Q)I(s,u,t))\\
&\left.+\frac{1}{8x_W^2}(\Theta(-Q)E(s,t,u)+\Theta(Q)E(s,u,t))\right\},\end{aligned} \tag{49.26}$$

where $\Theta(x)$ is 1 for $x > 0$ and 0 for $x < 0$, and where

$$A(s,t,u) = \left(\frac{tu}{m_W^4} - 1\right)\left(\frac{1}{4} - \frac{m_W^2}{s} + 3\frac{m_W^4}{s^2}\right) + \frac{s}{m_W^2} - 4,$$

$$I(s,t,u) = \left(\frac{tu}{m_W^4} - 1\right)\left(\frac{1}{4} - \frac{m_W^2}{2s} - \frac{m_W^4}{st}\right) + \frac{s}{m_W^2} - 2 + 2\frac{m_W^2}{t},$$

$$E(s,t,u) = \left(\frac{tu}{m_W^4} - 1\right)\left(\frac{1}{4} + \frac{m_W^4}{t^2}\right) + \frac{s}{m_W^2}, \qquad (49.27)$$

and s, t, u are the usual Mandelstam variables with $s = (p_f + p_{\overline{f}})^2, t = (p_f - p_{W^-})^2, u = (p_f - p_{W^+})^2$. The factor N_c is 3 for quarks and 1 for leptons.

The analogous cross-section for $q_i\overline{q}_j \to W^\pm Z^0$ is

$$\frac{d\sigma}{dt} = \frac{\pi\alpha^2|V_{ij}|^2}{6s^2x_W^2}\left\{\left(\frac{1}{s - m_W^2}\right)^2\left[\left(\frac{9 - 8x_W}{4}\right)\left(ut - m_W^2 m_Z^2\right)\right.\right.$$
$$\left. + (8x_W - 6)\, s\left(m_W^2 + m_Z^2\right)\right]$$
$$+ \left[\frac{ut - m_W^2 m_Z^2 - s(m_W^2 + m_Z^2)}{s - m_W^2}\right]\left[\frac{\ell_j}{t} - \frac{\ell_i}{u}\right]$$
$$\left. + \frac{ut - m_W^2 m_Z^2}{4(1 - x_W)}\left[\frac{\ell_j^2}{t^2} + \frac{\ell_i^2}{u^2}\right] + \frac{s(m_W^2 + m_Z^2)}{2(1 - x_W)}\frac{\ell_i \ell_j}{tu}\right\}, \qquad (49.28)$$

where ℓ_i and ℓ_j are the couplings of the left-handed q_i and q_j as defined above. The CKM matrix element between q_i and q_j is V_{ij}.

The cross section for $q_i\overline{q}_i \to Z^0 Z^0$ is

$$\frac{d\sigma}{dt} = \frac{\pi\alpha^2}{96}\frac{\ell_i^4 + r_i^4}{x_W^2(1 - x_W^2)^2 s^2}\left[\frac{t}{u} + \frac{u}{t} + \frac{4m_Z^2 s}{tu} - m_Z^4\left(\frac{1}{t^2} + \frac{1}{u^2}\right)\right]. \qquad (49.29)$$

49.5. Production of Higgs Bosons

49.5.1. *Resonant Production* :

The Higgs boson of the Standard Model can be produced resonantly in the collisions of quarks, leptons, W or Z bosons, gluons, or photons. The production cross section is thus controlled by the partial width of the Higgs boson into the entrance channel and its total width. The partial widths are given by the relations

$$\Gamma(H \to f\overline{f}) = \frac{G_F m_f^2 m_H N_c}{4\pi\sqrt{2}}\left(1 - 4m_f^2/m_H^2\right)^{3/2}, \qquad (49.30)$$

$$\Gamma(H \to W^+W^-) = \frac{G_F m_H^3 \beta_W}{32\pi\sqrt{2}}\left(4 - 4a_W + 3a_W^2\right), \qquad (49.31)$$

$$\Gamma(H \to ZZ) = \frac{G_F m_H^3 \beta_Z}{64\pi\sqrt{2}}\left(4 - 4a_Z + 3a_Z^2\right). \qquad (49.32)$$

where N_c is 3 for quarks and 1 for leptons and where $a_W = 1 - \beta_W^2 = 4m_W^2/m_H^2$ and $a_Z = 1 - \beta_Z^2 = 4m_Z^2/m_H^2$. The decay to two gluons proceeds through quark loops, with the t quark dominating. Explicitly,

$$\Gamma(H \to gg) = \frac{\alpha_s^2 G_F m_H^3}{36\pi^3\sqrt{2}} \left| \sum_q I(m_q^2/m_H^2) \right|^2 , \tag{49.33}$$

where $I(z)$ is complex for $z < 1/4$. For $z < 2 \times 10^{-3}$, $|I(z)|$ is small so the light quarks contribute negligibly. For $m_H < 2m_t$, $z > 1/4$ and

$$I(z) = 3 \left[2z + 2z(1-4z) \left(\sin^{-1} \frac{1}{2\sqrt{z}} \right)^2 \right] , \tag{49.34}$$

which has the limit $I(z) \to 1$ as $z \to \infty$.

49.5.2. *Higgs Boson Production in W^* and Z^* decay* :

The Standard Model Higgs boson can be produced in the decay of a virtual W or Z ("Higgstrahlung"): In particular, if k is the c.m. momentum of the Higgs boson,

$$\sigma(q_i\overline{q}_j \to WH) = \frac{\pi\alpha^2|V_{ij}|^2}{36\sin^4\theta_W} \frac{2k}{\sqrt{s}} \frac{k^2 + 3m_W^2}{(s-m_W^2)^2} \tag{49.35}$$

$$\sigma(f\overline{f} \to ZH) = \frac{2\pi\alpha^2(\ell_f^2 + r_f^2)}{48N_c\sin^4\theta_W\cos^4\theta_W} \frac{2k}{\sqrt{s}} \frac{k^2 + 3m_Z^2}{(s-m_Z^2)^2} . \tag{49.36}$$

where ℓ and r are defined as above.

49.5.3. *W and Z Fusion* :

Just as high-energy electrons can be regarded as sources of virtual photon beams, at very high energies they are sources of virtual W and Z beams. For Higgs boson production, it is the longitudinal components of the Ws and Zs that are important. The distribution of longitudinal Ws carrying a fraction y of the electron's energy is

$$f(y) = \frac{g^2}{16\pi^2} \frac{1-y}{y} , \tag{49.37}$$

where $g = e/\sin\theta_W$. In the limit $s \gg m_H \gg m_W$, the rate $\Gamma(H \to W_L W_L) = (g^2/64\pi)(m_H^3/m_W^2)$ and in the equivalent W approximation

$$\sigma(e^+e^- \to \overline{\nu}_e\nu_e H) = \frac{1}{16m_W^2} \left(\frac{\alpha}{\sin^2\theta_W} \right)^3 \times \left[\left(1 + \frac{m_H^2}{s} \right) \log \frac{s}{m_H^2} - 2 + 2\frac{m_H^2}{s} \right] . \tag{49.38}$$

There are significant corrections to this relation when m_H is not large compared to m_W. For $m_H = 150$ GeV, the estimate is too high by 51% for $\sqrt{s} = 1000$ GeV, 32% too high at $\sqrt{s} = 2000$ GeV, and 22% too high at $\sqrt{s} = 4000$ GeV. Fusion of ZZ to make a Higgs boson can be treated similarly. Identical formulae apply for Higgs production in the collisions of quarks whose charges permit the emission of a W^+ and a W^-, except that QCD corrections and CKM matrix elements are required. Even in the absence of QCD corrections, the fine-structure constant ought to be evaluated at the scale of the collision, say m_W. All quarks contribute to the ZZ fusion process.

Further discussion and all references may be found in the full *Review*; the equation and reference numbering corresponds to that version.

50. Neutrino Cross Section Measurements

Revised August 2017 by G.P. Zeller (Fermilab)

Highlights from full review.

Neutrino cross sections are an essential ingredient in all neutrino experiments. This work summarizes accelerator-based neutrino cross section measurements performed in the $\sim 0.1 - 300$ GeV range with an emphasis on inclusive, quasi-elastic, and pion production processes, areas where we have the most experimental input at present.

Table 50.1: List of modern accelerator-based neutrino experiments studying neutrino scattering.

Experiment	beam	$\langle E_{\nu,\overline{\nu}} \rangle$ GeV	target(s)	run period
ArgoNeuT	$\nu, \overline{\nu}$	4.3, 3.6	Ar	2009 – 2010
ICARUS	ν	20.0	Ar	2010 – 2012
K2K	ν	1.3	CH, H_2O	2003 – 2004
MicroBooNE	ν	0.8	Ar	2015 –
MINERvA	$\nu, \overline{\nu}$	3.5 (LE), 5.5 (ME)	He, C, CH, H_2O, Fe, Pb	2009 –
MiniBooNE	$\nu, \overline{\nu}$	0.8, 0.7	CH_2	2002 – 2012
MINOS	$\nu, \overline{\nu}$	3.5, 6.1	Fe	2004 – 2016
NOMAD	$\nu, \overline{\nu}$	23.4, 19.7	C–based	1995 – 1998
NOvA	$\nu, \overline{\nu}$	2.0, 2.0	CH_2	2010 –
SciBooNE	$\nu, \overline{\nu}$	0.8, 0.7	CH	2007 – 2008
T2K	ν, $\overline{\nu}$	0.6, 0.6	CH, H_2O, Fe	2010 –

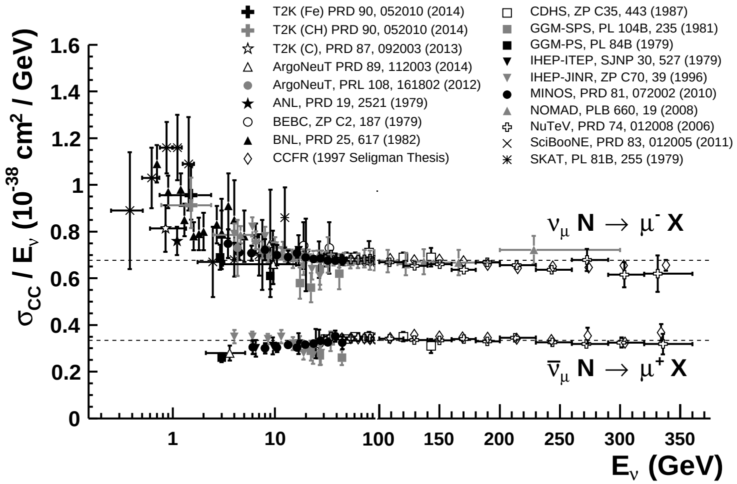


Figure 50.1: Measurements of per nucleon ν_μ and $\overline{\nu}_\mu$ CC inclusive scattering cross sections divided by neutrino energy as a function of neutrino energy. Note the transition between logarithmic and linear scales occurring at 100 GeV.

6. Atomic and Nuclear Properties of Materials

Table 6.1. Abridged from `pdg.lbl.gov/AtomicNuclearProperties` by D. E. Groom (2017). See web pages for more detail about entries in this table and for several hundred others. Quantities in parentheses are for gases at 20° C and 1 atm. Boiling points are at 1 atm. Refractive indices n are evaluated at the sodium D line blend (589.2 nm); values $\gg 1$ in brackets are for $(n-1) \times 10^6$ (gases) at 0° C and 1 atm.

Material	Z	A	$\langle Z/A \rangle$	Nucl.coll. length λ_T {g cm^{-2}}	Nucl.inter. length λ_I {g cm^{-2}}	Rad.len. X_0 {g cm^{-2}}	$dE/dx\|_{\min}$ { MeV g^{-1}cm^2}	Density {g cm^{-3}} ({g ℓ^{-1}})	Melting point (K)	Boiling point (K)	Refract. index @ Na D
H_2	1	1.008(7)	0.99212	42.8	52.0	63.05	(4.103)	0.071(0.084)	13.81	20.28	1.11[132.]
D_2	1	2.014101764(8)	0.49650	51.3	71.8	125.97	(2.053)	0.169(0.168)	18.7	23.65	1.11[138.]
He	2	4.002602(2)	0.49967	51.8	71.0	94.32	(1.937)	0.125(0.166)		4.220	1.02[35.0]
Li	3	6.94(2)	0.43221	52.2	71.3	82.78	1.639	0.534	453.6	1615.	
Be	4	9.0121831(5)	0.44384	55.3	77.8	65.19	1.595	1.848	1560.	2744.	
C diamond	6	12.0107(8)	0.49955	59.2	85.8	42.70	1.725	3.520			2.419
C graphite	6	12.0107(8)	0.49955	59.2	85.8	42.70	1.742	2.210	Sublimes at 4098. K		
N_2	7	14.007(2)	0.49976	61.1	89.7	37.99	(1.825)	0.807(1.165)	63.15	77.29	1.20[298.]
O_2	8	15.999(3)	0.50002	61.3	90.2	34.24	(1.801)	1.141(1.332)	54.36	90.20	1.22[271.]
F_2	9	18.998403163(6)	0.47372	65.0	97.4	32.93	(1.676)	1.507(1.580)	53.53	85.03	[195.]
Ne	10	20.1797(6)	0.49555	65.7	99.0	28.93	(1.724)	1.204(0.839)	24.56	27.07	1.09[67.1]
Al	13	26.9815385(7)	0.48181	69.7	107.2	24.01	1.615	2.699	933.5	2792.	
Si	14	28.0855(3)	0.49848	70.2	108.4	21.82	1.664	2.329	1687.	3538.	3.95
Cl_2	17	35.453(2)	0.47951	73.8	115.7	19.28	(1.630)	1.574(2.980)	171.6	239.1	[773.]
Ar	18	39.948(1)	0.45059	75.7	119.7	19.55	(1.519)	1.396(1.662)	83.81	87.26	1.23[281.]
Ti	22	47.867(1)	0.45961	78.8	126.2	16.16	1.477	4.540	1941.	3560.	
Fe	26	55.845(2)	0.46557	81.7	132.1	13.84	1.451	7.874	1811.	3134.	
Cu	29	63.546(3)	0.45636	84.2	137.3	12.86	1.403	8.960	1358.	2835.	
Ge	32	72.630(1)	0.44053	86.9	143.0	12.25	1.370	5.323	1211.	3106.	
Sn	50	118.710(7)	0.42119	98.2	166.7	8.82	1.263	7.310	505.1	2875.	
Xe	54	131.293(6)	0.41129	100.8	172.1	8.48	(1.255)	2.953(5.483)	161.4	165.1	1.39[701.]
W	74	183.84(1)	0.40252	110.4	191.9	6.76	1.145	19.300	3695.	5828.	
Pt	78	195.084(9)	0.39983	112.2	195.7	6.54	1.128	21.450	2042.	4098.	
Au	79	196.966569(5)	0.40108	112.5	196.3	6.46	1.134	19.320	1337.	3129.	
Pb	82	207.2(1)	0.39575	114.1	199.6	6.37	1.122	11.350	600.6	2022.	
U	92	[238.02891(3)]	0.38651	118.6	209.0	6.00	1.081	18.950	1408.	4404.	

Air (dry, 1 atm)	0.49919	61.3	90.1	36.62	(1.815)	(1.205)		78.80	
Shielding concrete	0.50274	65.1	97.5	26.57	1.711	2.300			
Borosilicate glass (Pyrex)	0.49707	64.6	96.5	28.17	1.696	2.230			
Lead glass	0.42101	95.9	158.0	7.87	1.255	6.220			
Standard rock	0.50000	66.8	101.3	26.54	1.688	2.650			
Methane (CH_4)	0.62334	54.0	73.8	46.47	(2.417)	(0.667)	90.68	111.7	[444.]
Butane (C_4H_{10})	0.59497	55.5	77.1	45.23	(2.278)	(2.489)	134.9	272.6	
Octane (C_8H_{18})	0.57778	55.8	77.8	45.00	2.123	0.703	214.4	398.8	
Paraffin ($CH_3(CH_2)_{n\approx 23}CH_3$)	0.57275	56.0	78.3	44.85	2.088	0.930			
Nylon (type 6, 6/6)	0.54790	57.5	81.6	41.92	1.973	1.18			
Polycarbonate (Lexan)	0.52697	58.3	83.6	41.50	1.886	1.20			
Polyethylene ($[CH_2CH_2]_n$)	0.57034	56.1	78.5	44.77	2.079	0.89			
Polyethylene terephthalate (Mylar)	0.52037	58.9	84.9	39.95	1.848	1.40			
Polyimide film (Kapton)	0.51264	59.2	85.5	40.58	1.820	1.42			
Polymethylmethacrylate (acrylic)	0.53937	58.1	82.8	40.55	1.929	1.19			1.49
Polypropylene	0.55998	56.1	78.5	44.77	2.041	0.90			
Polystyrene ($[C_6H_5CHCH_2]_n$)	0.53768	57.5	81.7	43.79	1.936	1.06			1.59
Polytetrafluoroethylene (Teflon)	0.47992	63.5	94.4	34.84	1.671	2.20			
Polyvinyltoluene	0.54141	57.3	81.3	43.90	1.956	1.03			1.58
Aluminum oxide (sapphire)	0.49038	65.5	98.4	27.94	1.647	3.970	2327.	3273.	1.77
Barium flouride (BaF_2)	0.42207	90.8	149.0	9.91	1.303	4.893	1641.	2533.	1.47
Carbon dioxide gas (CO_2)	0.49989	60.7	88.9	36.20	1.819	(1.842)			[449.]
Solid carbon dioxide (dry ice)	0.49989	60.7	88.9	36.20	1.787	1.563	Sublimes at 194.7 K		
Cesium iodide (CsI)	0.41569	100.6	171.5	8.39	1.243	4.510	894.2	1553.	1.79
Lithium fluoride (LiF)	0.46262	61.0	88.7	39.26	1.614	2.635	1121.	1946.	1.39
Lithium hydride (LiH)	0.50321	50.8	68.1	79.62	1.897	0.820	965.		
Lead tungstate ($PbWO_4$)	0.41315	100.6	168.3	7.39	1.229	8.300	1403.		2.20
Silicon dioxide (SiO_2, fused quartz)	0.49930	65.2	97.8	27.05	1.699	2.200	1986.	3223.	1.46
Sodium chloride (NaCl)	0.47910	71.2	110.1	21.91	1.847	2.170	1075.	1738.	1.54
Sodium iodide (NaI)	0.42697	93.1	154.6	9.49	1.305	3.667	933.2	1577.	1.77
Water (H_2O)	0.55509	58.5	83.3	36.08	1.992	1.000(0.756)	273.1	373.1	1.33
Silica aerogel	0.50093	65.0	97.3	27.25	1.740	0.200	(0.03 H_2O, 0.97 SiO_2)		

Table 4.1. Revised June 2017 by D.E. Groom (LBNL). The atomic number (top left) is the number of protons in the nucleus. The atomic masses (bottom) of stable elements are weighted by isotopic abundances in the Earth's surface. Atomic masses are relative to the mass of ^{12}C, defined to be exactly 12 unified atomic mass units (u) (1 u $\approx$ 1 g/mole). The exceptions are Th, Pa, and U, which have no stable isotopes but do have characteristic terrestrial compositions. Relative isotopic abundances often vary considerably, both in natural and commercial samples; this is reflected in the number of significant figures given for the mass. Masses may be found at `http://physics.nist.gov/pml/atomic-weights-and-isotopic-compositions-relative-atomic-masses`. If there is no stable isotope, the atomic mass of the most stable isotope is given in parentheses.

PERIODIC TABLE OF THE ELEMENTS

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H hydrogen 1.008																	2 He helium 4.002602
3 Li lithium 6.94	4 Be beryllium 9.012182											5 B boron 10.81	6 C carbon 12.0107	7 N nitrogen 14.007	8 O oxygen 15.999	9 F fluorine 18.998403163	10 Ne neon 20.1797
11 Na sodium 22.98976928	12 Mg magnesium 24.305											13 Al aluminum 26.9815385	14 Si silicon 28.085	15 P phosph. 30.973761998	16 S sulfur 32.06	17 Cl chlorine 35.45	18 Ar argon 39.948
19 K potassium 39.0983	20 Ca calcium 40.078	21 Sc scandium 44.955908	22 Ti titanium 47.867	23 V vanadium 50.9415	24 Cr chromium 51.9961	25 Mn manganese 54.938044	26 Fe iron 55.845	27 Co cobalt 58.933195	28 Ni nickel 58.6934	29 Cu copper 63.546	30 Zn zinc 65.38	31 Ga gallium 69.723	32 Ge german. 72.630	33 As arsenic 74.921595	34 Se selenium 78.971	35 Br bromine 79.904	36 Kr krypton 83.798
37 Rb rubidium 85.4678	38 Sr strontium 87.62	39 Y yttrium 88.90584	40 Zr zirconium 91.224	41 Nb niobium 92.90637	42 Mo molybd. 95.95	43 Tc technet. (97.907212)	44 Ru ruthen. 101.07	45 Rh rhodium 102.90550	46 Pd palladium 106.42	47 Ag silver 107.8682	48 Cd cadmium 112.414	49 In indium 114.818	50 Sn tin 118.710	51 Sb antimony 121.760	52 Te tellurium 127.60	53 I iodine 126.90447	54 Xe xenon 131.293
55 Cs cesium 132.90545196	56 Ba barium 137.327	57–71 Lantha- nides	72 Hf hafnium 178.49	73 Ta tantalum 180.94788	74 W tungsten 183.84	75 Re rhenium 186.207	76 Os osmium 190.23	77 Ir iridium 192.217	78 Pt platinum 195.084	79 Au gold 196.966569	80 Hg mercury 200.592	81 Tl thallium 204.38	82 Pb lead 207.2	83 Bi bismuth 208.98040	84 Po polonium (208.98243)	85 At astatine (209.98715)	86 Rn radon (222.01758)
87 Fr francium (223.01974)	88 Ra radium (226.02541)	89–103 Actinides	104 Rf rutherford. (267.12169)	105 Db dubnium (268.12567)	106 Sg seaborgium (269.12863)	107 Bh bohrium (270.13336)	108 Hs hassium (269.13375)	109 Mt meitnerium (278.1563)	110 Ds darmstadt. (281.1645)	111 Rg roentgen. (282.16912	112 Cn copernicium (285.17712)	113 Nh (nihonium) (286.18221)	114 Fl flerovium (289.19042)	115 Mc (moscovium) (289.19363)	116 Lv livermorium (294.2105)	117 Ts (tennessine) (294.2105)	118 Og (oganesson) (294.21392)

Lanthanide series	57 La lanthan. 138.90547	58 Ce cerium 140.116	59 Pr praseodym. 140.90765	60 Nd neodym. 144.242	61 Pm prometh. (144.91276)	62 Sm samarium 150.36	63 Eu europium 151.964	64 Gd gadolin. 157.25	65 Tb terbium 158.92535	66 Dy dyspros. 162.500	67 Ho holmium 164.93033	68 Er erbium 167.259	69 Tm thulium 168.93422	70 Yb ytterbium 173.054	71 Lu lutetium 174.9668
Actinide series	89 Ac actinium (227.02775)	90 Th thorium 232.0377	91 Pa protactin. 231.03588	92 U uranium 238.02891	93 Np neptunium (237.04817)	94 Pu plutonium (244.06420)	95 Am americ. (243.06138)	96 Cm curium (247.07035)	97 Bk berkelium (247.07031)	98 Cf californ. (251.07959)	99 Es einstein. (252.08298)	100 Fm fermium (257.09511)	101 Md mendelev. (258.09844)	102 No nobelium (259.10103)	103 Lr lawrenc. (262.10961)

2018

JULY

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

AUGUST

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

SEPTEMBER

S	M	T	W	T	F	S
						1
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9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

OCTOBER

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

NOVEMBER

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

DECEMBER

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

2019

JANUARY

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

FEBRUARY

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28		

MARCH

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					1	2
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24	25	26	27	28	29	30
31						

APRIL

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MAY

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19	20	21	22	23	24	25
26	27	28	29	30	31	

JUNE

S	M	T	W	T	F	S
						1
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9	10	11	12	13	14	15
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2019

JULY

S	M	T	W	T	F	S
	1	2	3	4	5	6
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21	22	23	24	25	26	27
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AUGUST

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11	12	13	14	15	16	17
18	19	20	21	22	23	24
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SEPTEMBER

S	M	T	W	T	F	S
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8	9	10	11	12	13	14
15	16	17	18	19	20	21
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OCTOBER

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NOVEMBER

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24	25	26	27	28	29	30

DECEMBER

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8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
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2020

JANUARY

S	M	T	W	T	F	S
			1	2	3	4
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19	20	21	22	23	24	25
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FEBRUARY

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16	17	18	19	20	21	22
23	24	25	26	27	28	29

MARCH

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APRIL

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26	27	28	29	30		

MAY

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24	25	26	27	28	29	30
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JUNE

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21	22	23	24	25	26	27
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Prepared for the U.S. Department of Energy
under Contract DE-AC02-05CH11231